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Aurorae are a must-see astronomical phenomenon

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Welcome

Some weeks ago I was sitting with the **All About Space** team, talking about a new theory that seems to have been rattling around the scientific community for quite a few years: the rumour among astrophysicists is that our universe - and any other universes that surround us - could be inside a gravastar. Eyebrows were raised. How could we actually prove it? What made astrophysicists think that this could be a possibility? What actually is a gravastar? This issue **All About Space** finds out - turn to page 50 for everything you need to know as we unlock the evidence that's left cosmologists questioning what's at the very edge of the cosmos as we know it.

The hunt for another world within our Solar System is still going strong, as you'll discover on page 16. And, with the search being restarted in earnest with current and new technologies and missions, it could only be a matter of time before we finally lock on to another planet for us to explore.

Could it be just as we imagined? How big is it? Could we send a spacecraft there? All might be revealed in the next few years or so. If you haven't already, we hope you enjoy your free gift with this issue, and don't forget to make the most of our latest offer which entitles you to a year's subscription plus five books that will assist in your exploration of the night sky and space.

Gemma Lavender
Editor-in-Chief

Our contributors include...

James Romero
Science writer
Do we live in a gravastar? James gets on the trail of the cosmologists with the answers this issue. Turn to page 50 for everything you need to know.

Lee Cavendish
Staff Writer & astronomer
When neutron stars collide. Find out what the discovery of the greatest explosion in the universe means - Lee has the details over on page 64.

Alfred Worden
Former NASA astronaut
The Apollo 15 Command Module pilot joins our team of planetary scientists, astronomers and astrophysicists to answer your questions.

Stuart Atkinson
Astronomer
Ever wanted to start your own astronomical society? Stuart shows you how in 20 easy steps that'll have you successfully hosting under the skies.

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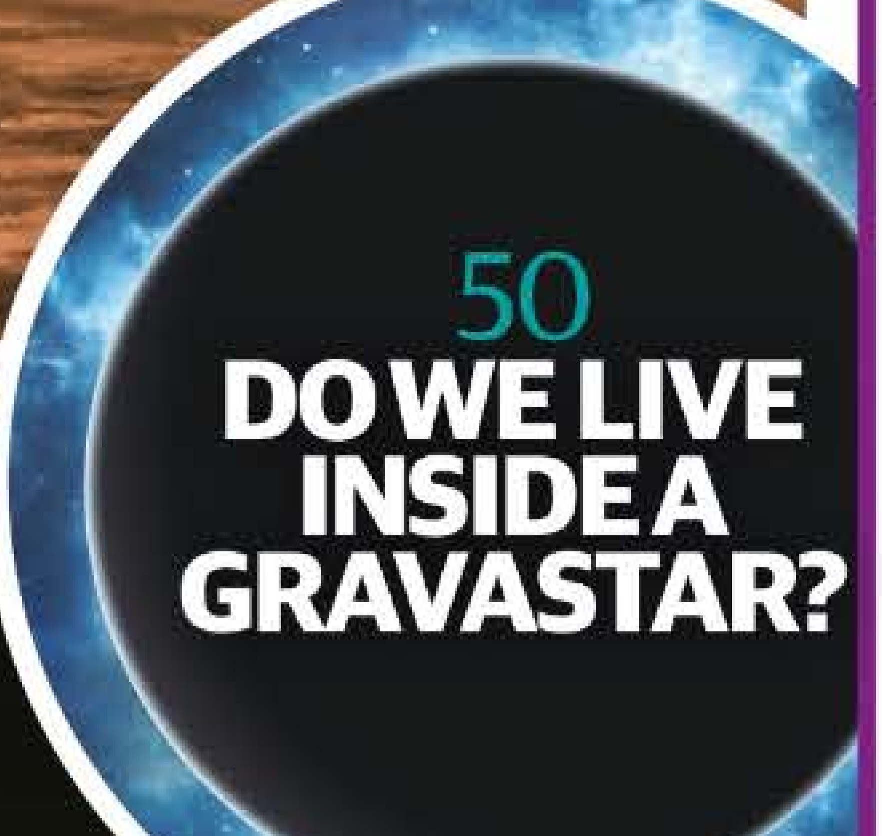

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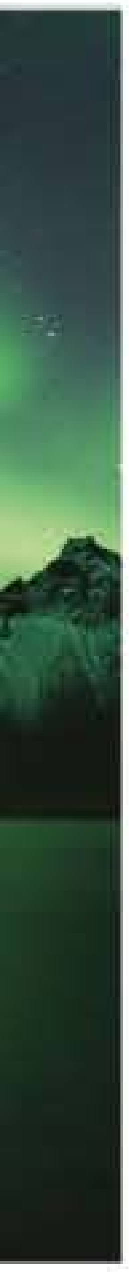

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Wonders of the Atacama Desert

Sitting under the arc of the Milky Way is one of the Auxiliary Telescopes that constitutes the European Southern Observatory's (ESO) Very Large Telescope (VLT). This amazing array of dishes has led to some of the most inspiring results from some of the darkest corners of the universe. Not only that, it has contributed heavily to many scientific studies.

However, looking at it from the outside reveals some breathtaking views as well. Its location at the Paranal Observatory in the Chilean Atacama Desert presents ideal conditions for night-sky observing due to the vast dry climate (inset image), combined with thin atmosphere.

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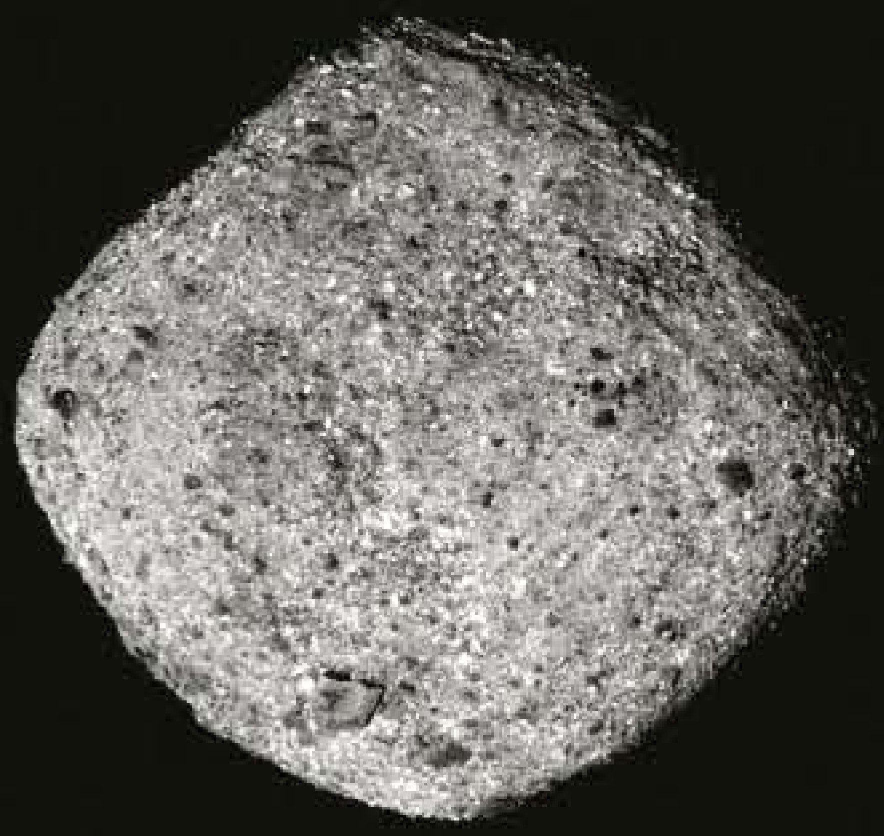

Approach to Bennu

NASA's long-awaited Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) has completed its 2 billion-kilometre (1.2 billion-mile) journey through the Solar System to the asteroid Bennu.

After this image was taken on its approach at 80 kilometres (50 miles), OSIRIS-REx executed a manoeuvre that took it into a close orbit around the asteroid in order to investigate what these primordial time-capsules can tell us about our early Solar System.

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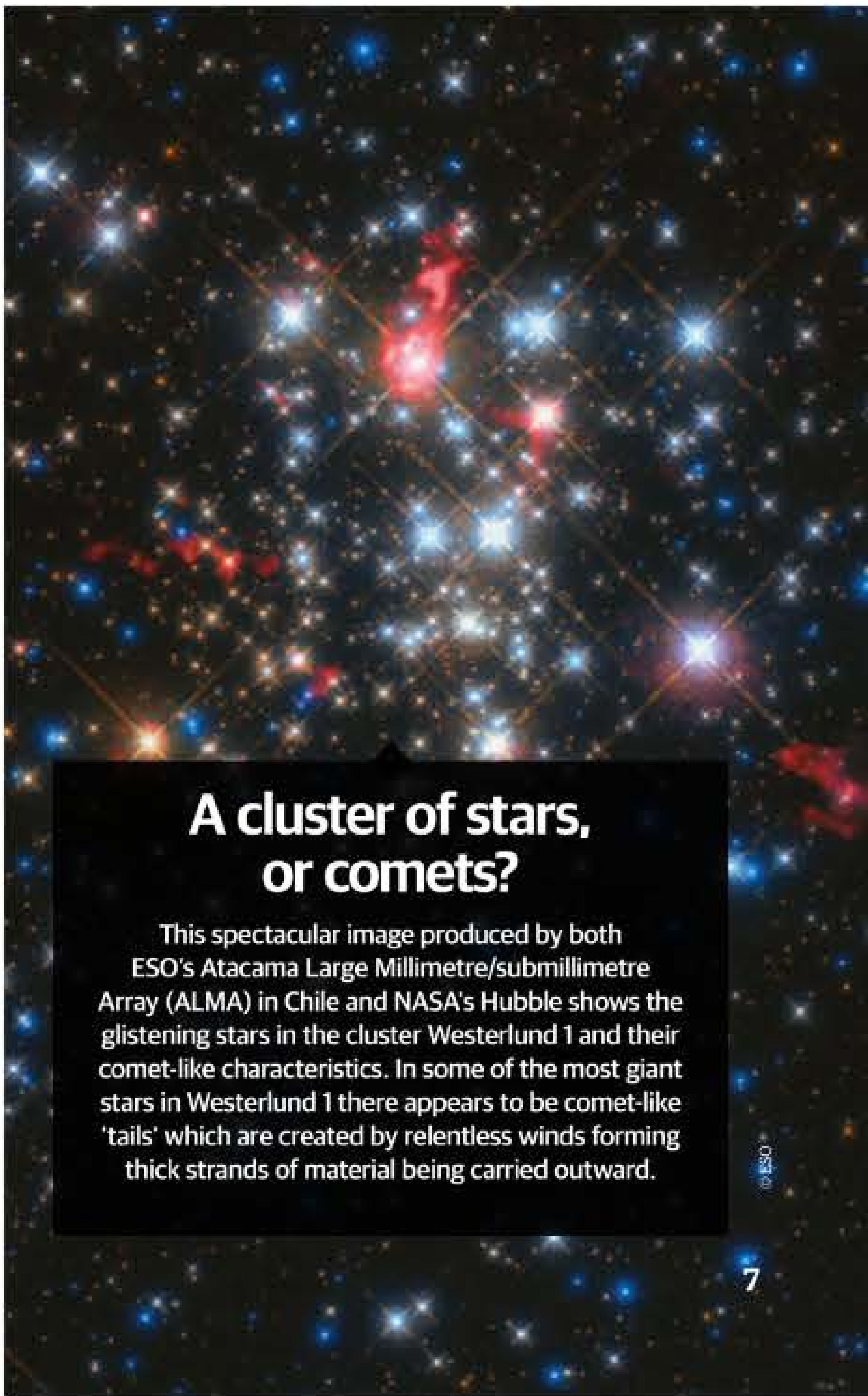

A cluster of stars, or comets?

This spectacular image produced by both ESO's Atacama Large Millimetre/submillimetre Array (ALMA) in Chile and NASA's Hubble shows the glistening stars in the cluster Westerlund 1 and their comet-like characteristics. In some of the most giant stars in Westerlund 1 there appears to be comet-like 'tails' which are created by relentless winds forming thick strands of material being carried outward.

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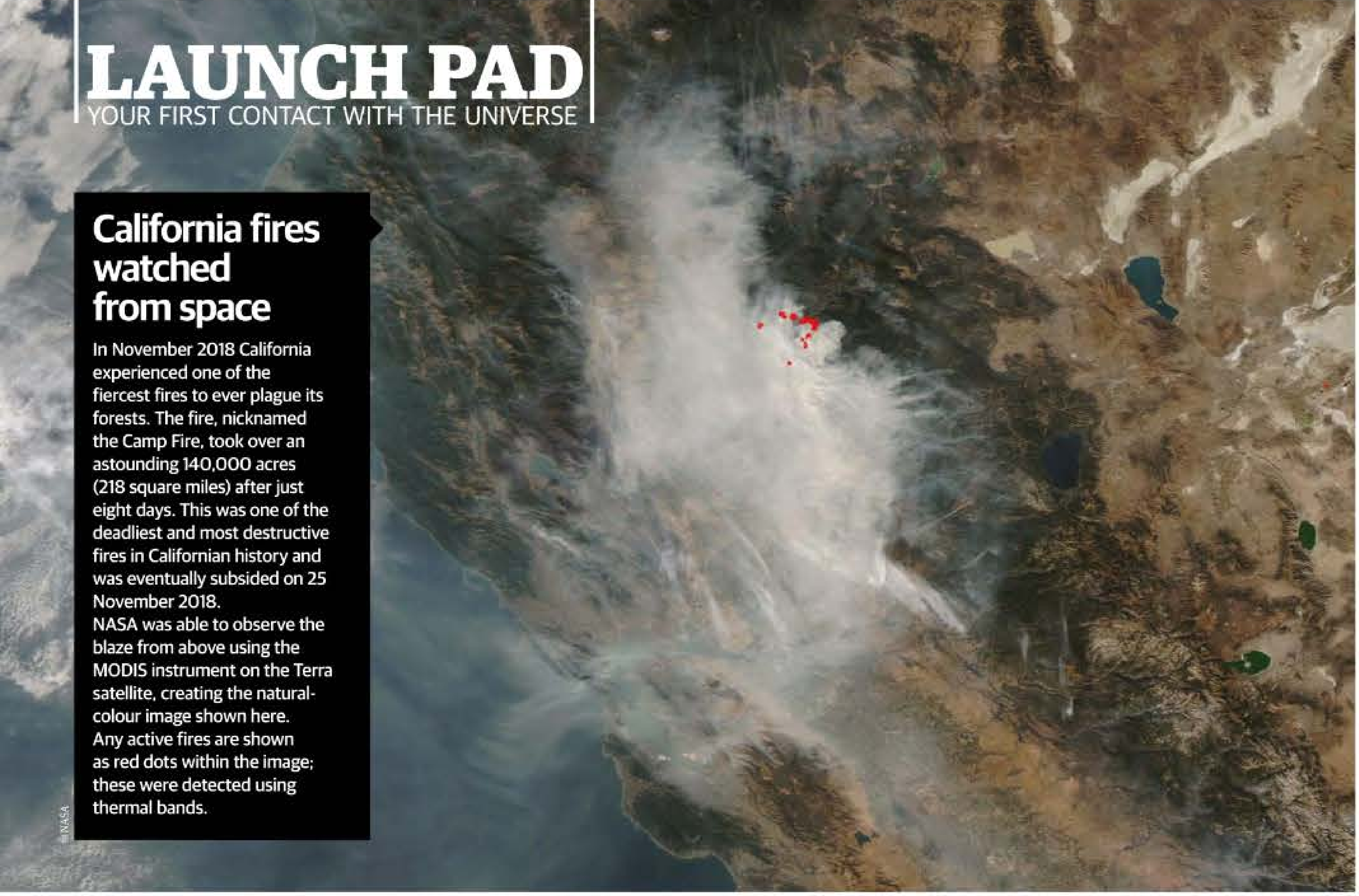

California fires watched from space

In November 2018 California experienced one of the fiercest fires to ever plague its forests. The fire, nicknamed the Camp Fire, took over an astounding 140,000 acres (218 square miles) after just eight days. This was one of the deadliest and most destructive fires in Californian history and was eventually subsided on 25 November 2018.

NASA was able to observe the blaze from above using the MODIS instrument on the Terra satellite, creating the natural-colour image shown here. Any active fires are shown as red dots within the image; these were detected using thermal bands.

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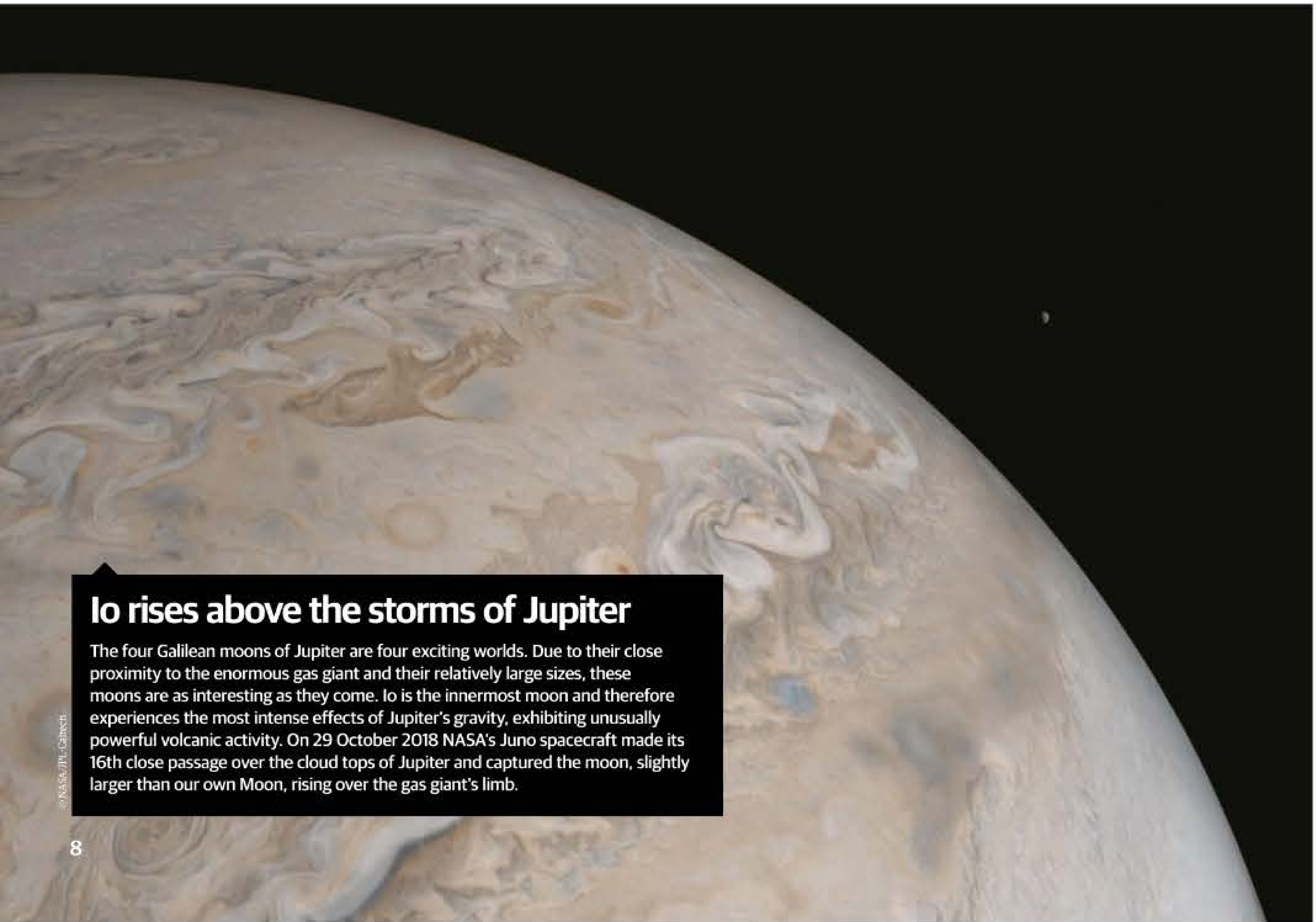
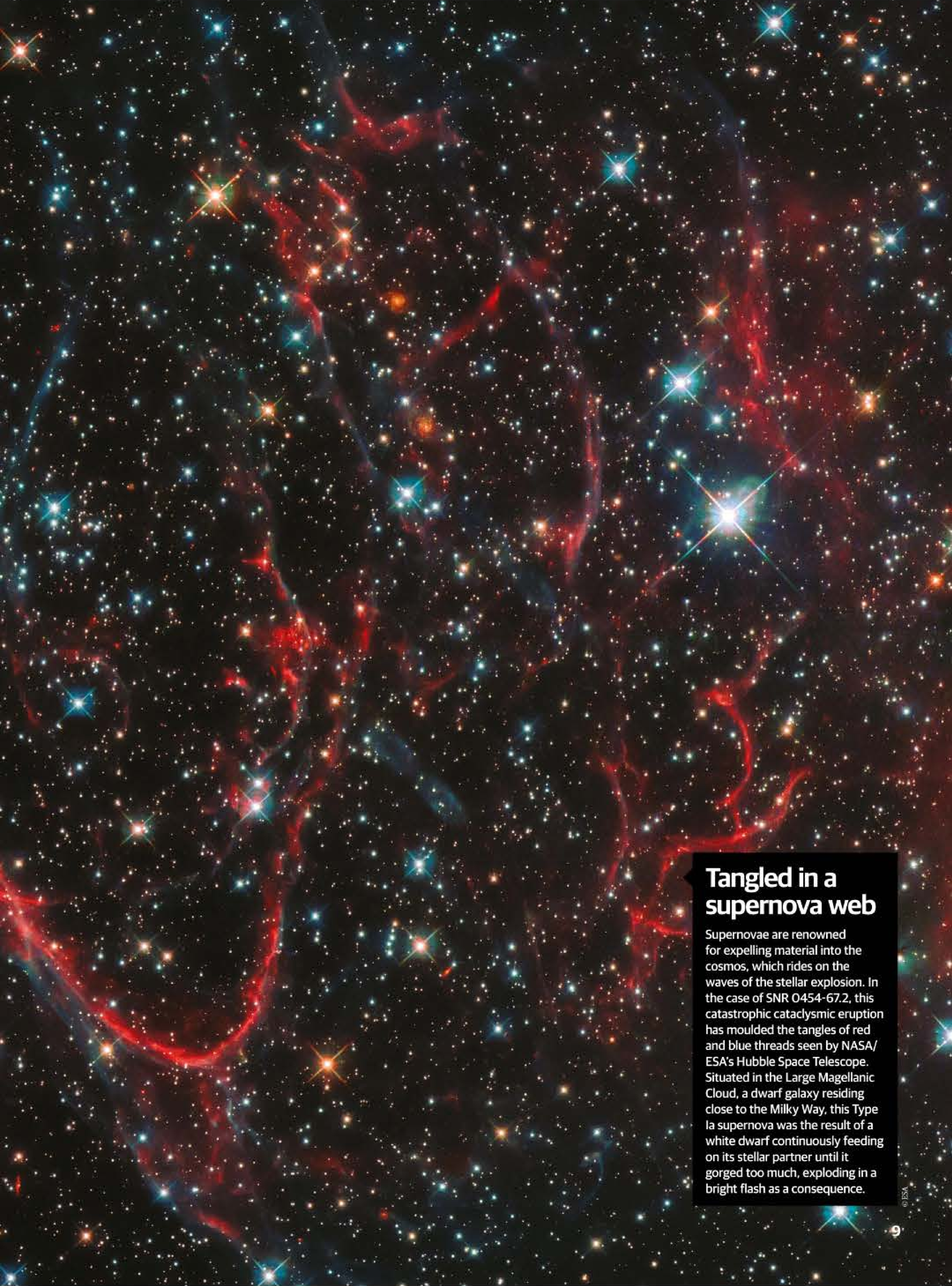


Io rises above the storms of Jupiter

The four Galilean moons of Jupiter are four exciting worlds. Due to their close proximity to the enormous gas giant and their relatively large sizes, these moons are as interesting as they come. Io is the innermost moon and therefore experiences the most intense effects of Jupiter's gravity, exhibiting unusually powerful volcanic activity. On 29 October 2018 NASA's Juno spacecraft made its 16th close passage over the cloud tops of Jupiter and captured the moon, slightly larger than our own Moon, rising over the gas giant's limb.

© NASA/JPL-Caltech



Tangled in a supernova web

Supernovae are renowned for expelling material into the cosmos, which rides on the waves of the stellar explosion. In the case of SNR 0454-67.2, this catastrophic cataclysmic eruption has moulded the tangles of red and blue threads seen by NASA/ESA's Hubble Space Telescope. Situated in the Large Magellanic Cloud, a dwarf galaxy residing close to the Milky Way, this Type Ia supernova was the result of a white dwarf continuously feeding on its stellar partner until it gorged too much, exploding in a bright flash as a consequence.

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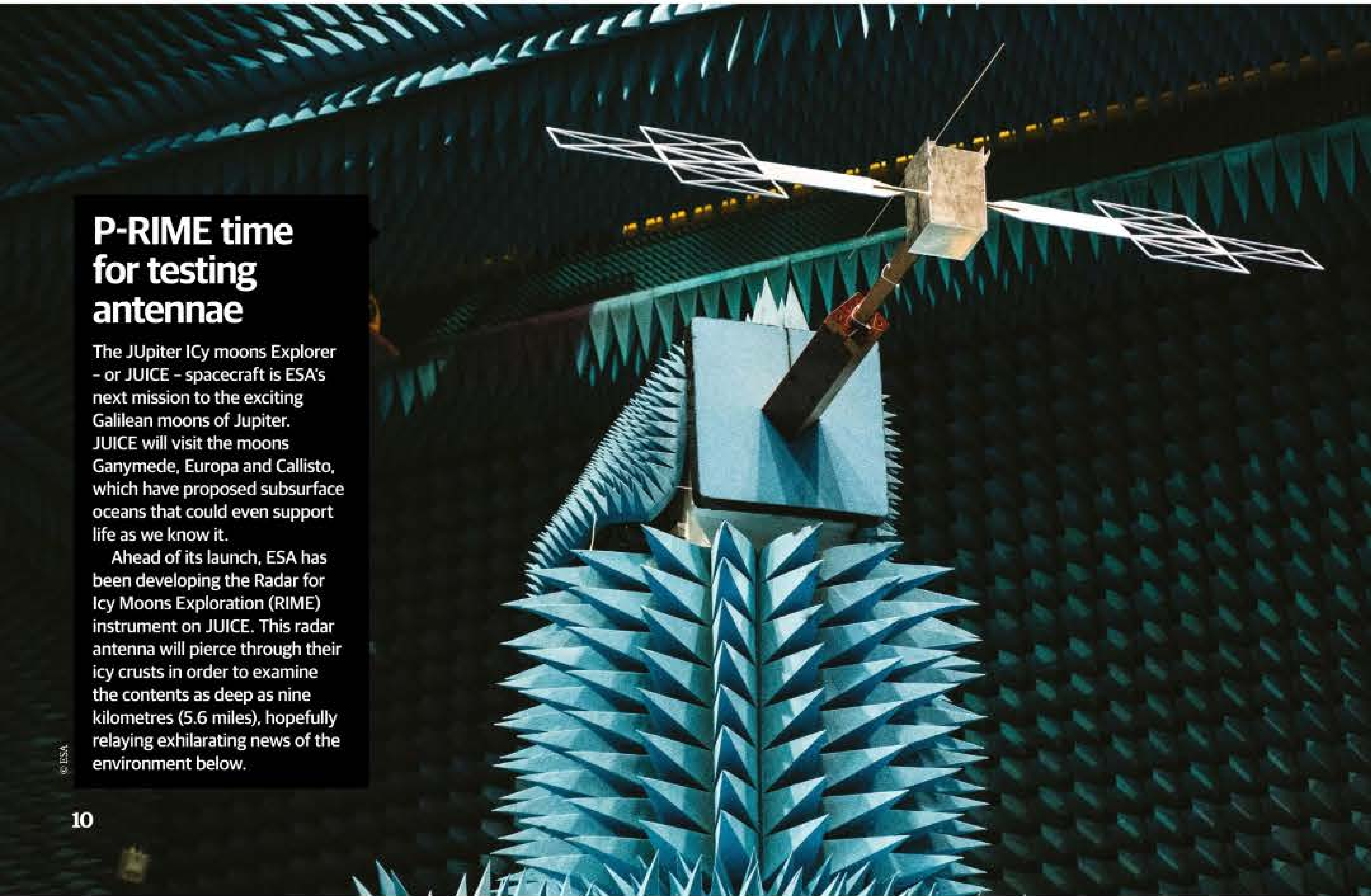
Experimental aviation

During a test with an F/A-18 research aircraft this image of Earth's curvature was taken from the cockpit while performing a series of quiet supersonic dives over the coast of Galveston, Texas. The pilot climbed 15,000 metres (50,000 feet) before performing the dive. Scientists want to carefully study the shockwaves created to improve future models of the X-59 QueSST aircraft.



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P-RIME time for testing antennae

The JUpiter ICy moons Explorer - or JUICE - spacecraft is ESA's next mission to the exciting Galilean moons of Jupiter. JUICE will visit the moons Ganymede, Europa and Callisto, which have proposed subsurface oceans that could even support life as we know it.

Ahead of its launch, ESA has been developing the Radar for Icy Moons Exploration (RIME) instrument on JUICE. This radar antenna will pierce through their icy crusts in order to examine the contents as deep as nine kilometres (5.6 miles), hopefully relaying exhilarating news of the environment below.

ExoMars under the Spanish Sun

As the Sun set on a week of trials for the European Space Agency's (ESA) ExoMars rover prototype, nicknamed Charlie, scientists are excited about what is to come from the future mission.

During a ten-day field trial taken in the Tabernas Desert in Spain, nicknamed ExoFiT, scientists were practising driving the rover, targeting areas of interest and sampling rocks. Although there were environmental issues such as rainfall the team were able to optimise their time and test a variety of instruments that will search for signs of life on the surface of Mars.

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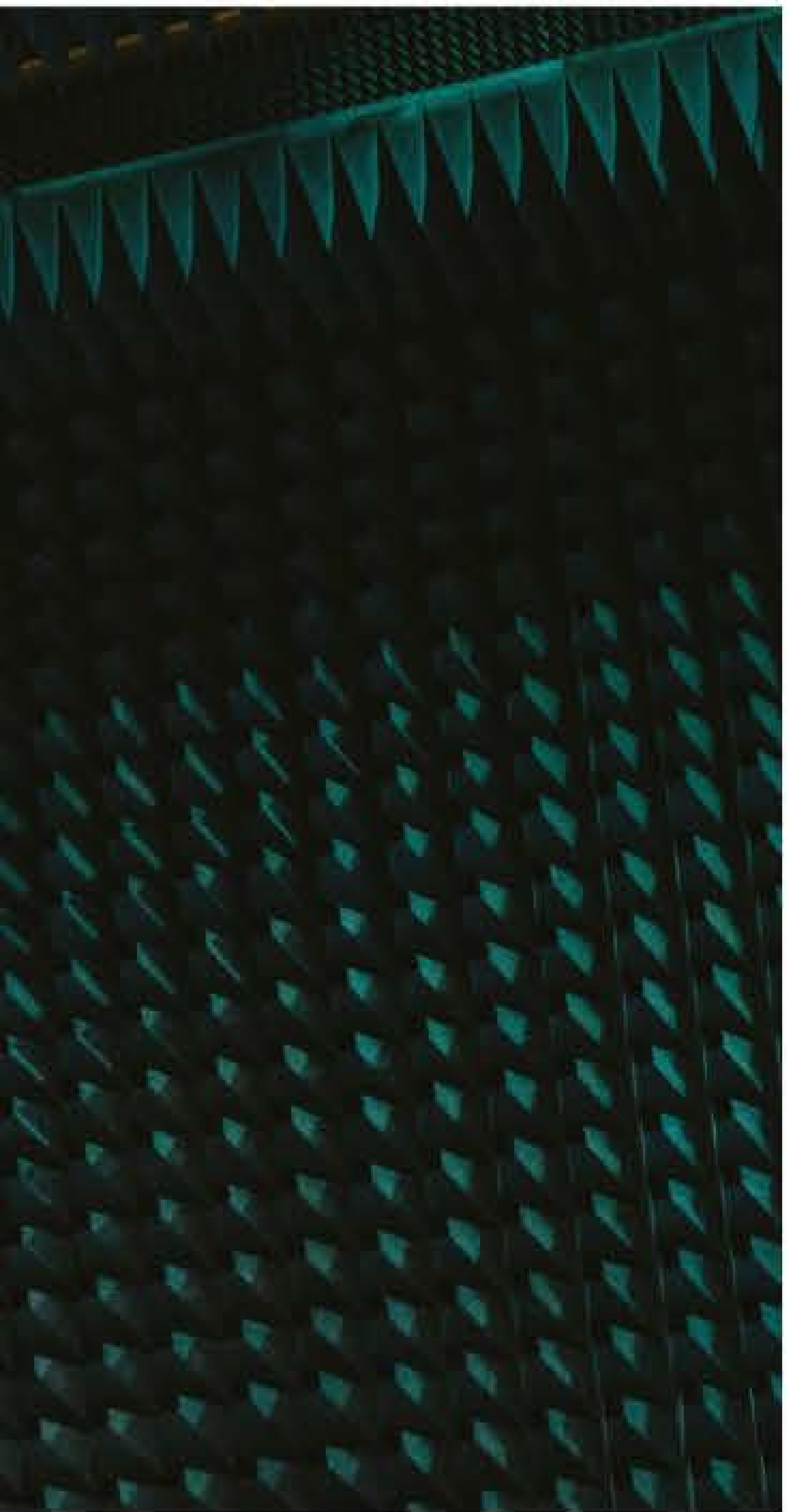

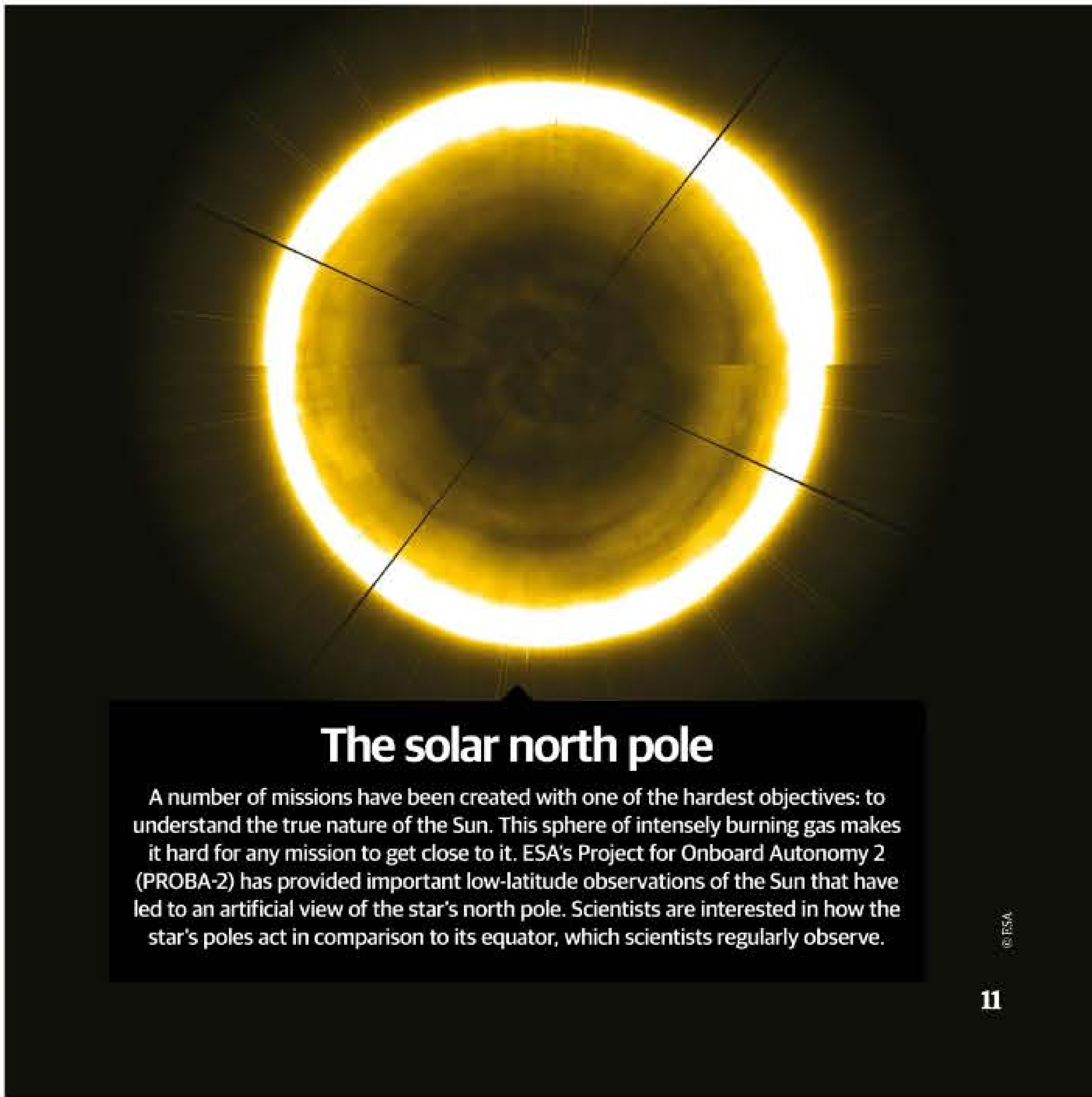

The solar north pole

A number of missions have been created with one of the hardest objectives: to understand the true nature of the Sun. This sphere of intensely burning gas makes it hard for any mission to get close to it. ESA's Project for Onboard Autonomy 2 (PROBA-2) has provided important low-latitude observations of the Sun that have led to an artificial view of the star's north pole. Scientists are interested in how the star's poles act in comparison to its equator, which scientists regularly observe.

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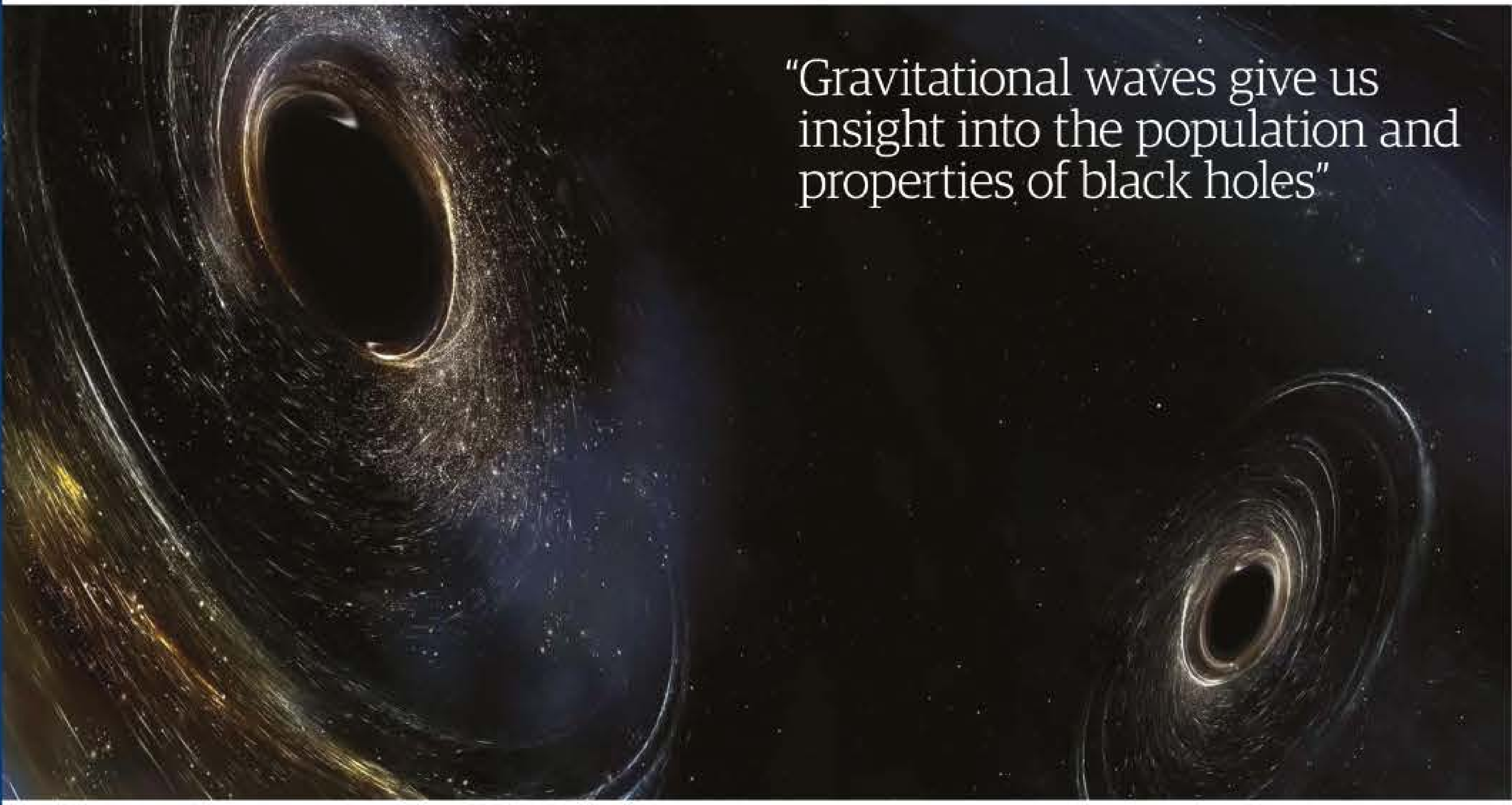


"Gravitational waves give us insight into the population and properties of black holes"

Four new kinds of gravitational waves detected from crashing black holes

It's the largest batch of detections released at once and includes an event that is both the most massive and the most distant collision observed to date

Words by **Meghan Bartels**

Scientists have identified four more signals of massive collisions in outer space, including the largest to date, bringing the total of gravitational-wave detections to 11 in just a few years.

A team of researchers affiliated with the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the US and its European counterpart Virgo unveiled the four new detections on Saturday 1 December at a scientific meeting. "It took science a century to confirm Einstein's prediction of the existence of gravitational waves," Sheila Rowan, a physicist at the University of Glasgow, says. "The pace of our discoveries since then has been exhilarating, and we're anticipating many more exciting detections to come."

Gravitational waves are often described as ripples in space-time and are produced by pairs of black holes or neutron stars - two forms of extremely massive, dense remnants created when a star explodes. Pairs of these objects orbit each other, drawing ever closer to one another and causing gravitational waves to ripple outward as they do so until they eventually collide.

Thanks to the LIGO and Virgo detectors scientists on Earth can now capture these signals, which lets them study the collisions and objects involved. As the field of gravitational-wave science has matured, new detections have taken on a different tone. The first detection, which was announced in February of 2016, was remarkable for its very existence, but in the nearly three intervening years binary black hole mergers have begun to verge on the routine.

The new announcement is the largest batch of detections released at once, and it includes an event that is both the most massive and the most distant collision observed to date. And now that scientists have a total of ten binary black hole merger detections under their belts, as well as one binary neutron star merger, announced last autumn, they can start to draw some conclusions about black holes in general.

"Gravitational waves give us unprecedented insight into the population and properties of black holes," Chris Pankow, an astrophysicist at Northwestern University, Illinois, says - for example, that most black holes formed by stars encompass less than 45 Suns' of material. "We now have a sharper picture of both how frequently stellar mass binary black holes merge and what their masses are. These measurements will further enable us to understand how the most massive stars of our universe are born, live and die."

© NASA; LIGO/Caltech; CIMON; Mark A. Garlick / space-art.co.uk

Planets around double stars could boast life-friendly moons

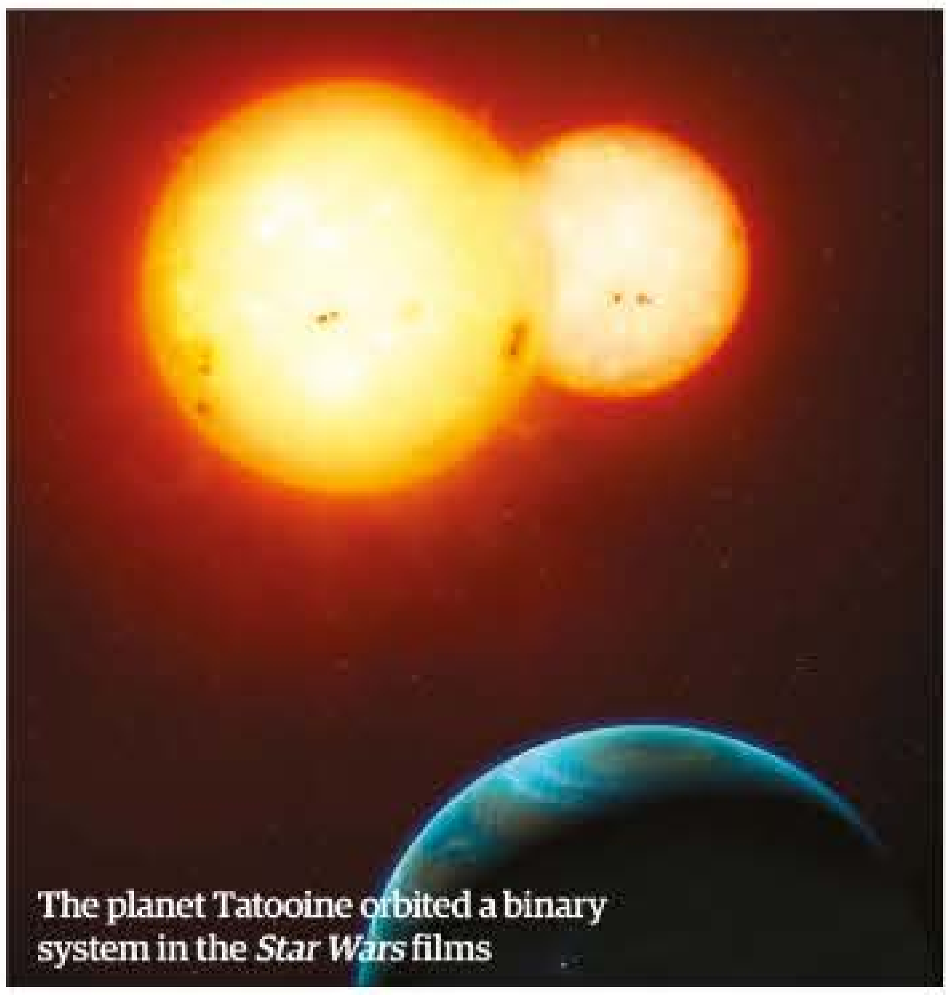
Researchers in the new study were particularly interested in the newfound Kepler planets Words by **Nola Taylor Redd**

New research suggests that planets orbiting pairs of stars could hold on to their moons, creating sites for life to evolve. Double-star systems can create a challenge in stability that their single-star cousins avoid, however. In both systems the stars move around slightly, potentially disturbing any orbiting planets and their moons. When two stars are dancing together it increases the odds that the stars will knock away a planet, as well as its moon.

"Stability is the first requirement for habitability," Adrian Hamers, a planetary theorist at the Institute for Advanced Study in Princeton, New Jersey, explains. With his colleagues, Hamers modelled the stability of the ten confirmed exoplanets orbiting binary stars that have been identified by NASA's Kepler Space Telescope. The researchers calculated the regions of stability where exomoons could be detected using future instruments. "If the orbit of the exomoon is not stable then, in extreme cases, it will be flung out of the system," Hamers says.

While exomoons of planets that orbit a single star are a well-studied phenomenon, Hamers says, less work has been done for exomoons in binary systems. Circumbinary worlds have been discovered using other telescopes, but the researchers in the new study were particularly interested in the newfound Kepler planets. "We were curious which orbits of exomoons around these circumbinary planets would be dynamically stable," Hamers says.

The scientists ran multiple simulations of the moons of planets around stellar pairs. Results showed that stable simulated moons remained close to their planets, at about 0.01 AU (1 AU being the Earth-Sun distance) apart, so that these moons were less affected by the gravity of the stellar pairs. Moons were also more stable when they circled more massive planets. The angle of the moon's path around the planet compared to the planet's path around the suns proved important as well. When a moon circled at a 90-degree angle compared to the planetary path the moon oscillated widely before becoming unstable, crashing into the planet or, on rare occasions, one of the stars.



The planet Tatooine orbited a binary system in the *Star Wars* films

International Space Station welcomes AI robot

CIMON could save astronauts a lot of time during experiments and help them perform more efficiently Words by **Tereza Pultarova**

The Space Station robot CIMON has exchanged its first words with its spacefaring crew. German astronaut Alexander Gerst spoke with the artificially intelligent crew assistant during a 90-minute experiment on 15 November aboard the International Space Station (ISS).

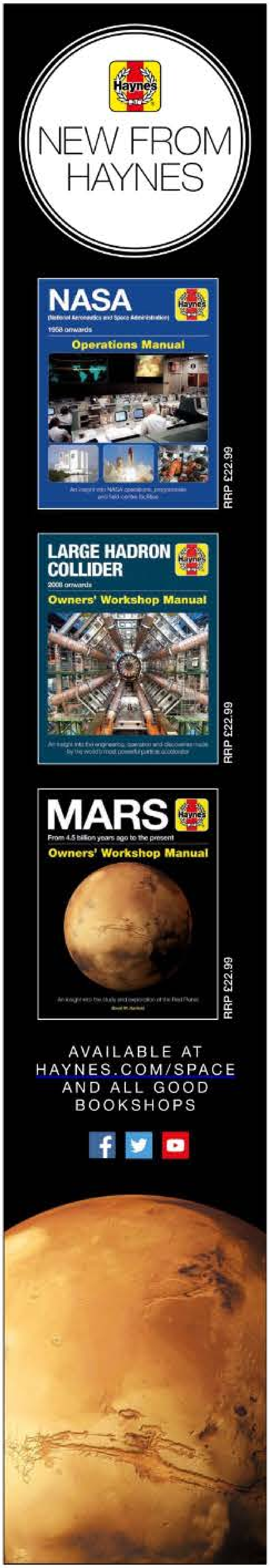
According to a statement from the manufacturer, Airbus, Gerst, the commander of the current space station crew, woke up CIMON (the Crew Interactive Mobile CompanioN) with the words "Wake up, CIMON." In response CIMON said, "What can I do for you?" During the experiment CIMON successfully found and recognised Gerst's face, took photos and video, positioned itself autonomously within the Columbus module using its ultrasonic sensors and issued instructions for Gerst to perform a student-designed experiment with crystals.

CIMON is able to give out experiment instuctions

Weighing about five kilograms (11 pounds) on Earth, the 3D-printed robot, designed jointly by the German space agency DLR, Airbus and IBM, works similarly to Apple's virtual assistant Siri or Amazon's Alexa. CIMON doesn't process commands itself, but instead communicates with a ground-based cloud computer - IBM's natural language-processing computer, Watson.

"If CIMON is asked a question or addressed, the Watson AI firstly converts this audio signal into text, which is understood, or interpreted, by the AI," explains IBM project lead Matthias Biniok in the statement. "IBM Watson not only understands content in context, it can also understand the intention behind it."

The computer provides a tailored answer to an astronaut's query, and this answer is then converted into speech and beamed back to the ISS. CIMON is connected to the ISS Wi-Fi network that transmits data via satellite connections to the ground.



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Nearby planet probably wet and life-friendly

TRAPPIST-1e may host liquid water on its surface Words by **Samantha Matthewson**

One of seven planets orbiting a small star, TRAPPIST-1, may be capable of supporting life, new climate models suggest. Using terrestrial climate and photochemistry models, researchers from the University of Washington simulated environmental states for each planet of the TRAPPIST-1 system. The models show that all seven exoplanets likely evolved like Venus, meaning that any water or oceans would have evaporated early on in the system's formation, the research team said.

According to these models the seven planets of TRAPPIST-1 would have dense, uninhabitable atmospheres. However, one of the worlds, TRAPPIST-1e, may host liquid water on its surface and, as a result, be able to support Earth-like life.

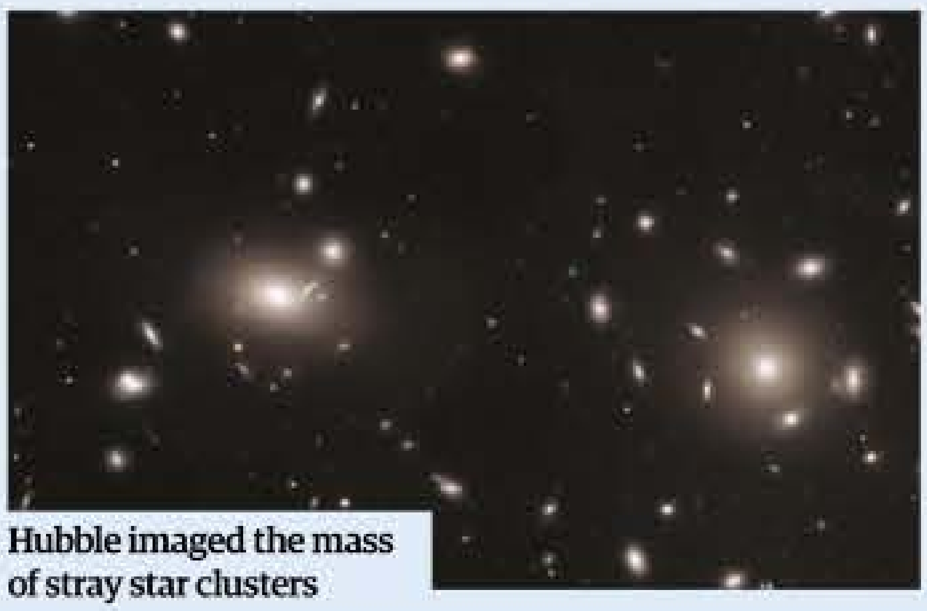
This planet may also have a lot of oxygen. As water evaporates from a planet's surface and is zapped by a star's ultraviolet emissions the hydrogen and oxygen molecules split, according to the statement. The hydrogen can be light enough to leave the atmosphere despite the planet's gravity, but oxygen will linger. TRAPPIST-1e could have a thick oxygen atmosphere formed through processes that are far different from anything yet observed. "This may be possible if these planets had more water initially than Earth, Venus or Mars," says Andrew Lincowski of the University of Washington. "If TRAPPIST-1e did not lose all of its water during this phase, today it could be a water world, completely covered by a global ocean. In this case it could have a climate similar to Earth."

Hubble spots drifting orphaned stars

Over 22,400 globular clusters have been spotted Words by **Hanneke Weitering**

An enormous cosmic neighbourhood that's home to more than 1,000 gravitationally bound galactic neighbours is bursting with thousands of stray star clusters, images from the Hubble Space Telescope have revealed.

While conducting a comprehensive survey of the Coma Cluster of galaxies astronomers using the Hubble Space Telescope counted 22,426 globular star clusters scattered throughout the space between those galaxies. Each of those dense, spherical groups contains hundreds of thousands of ancient stars that huddle together because of their mutual gravitational attraction, much like the larger galaxies that make up the Coma Cluster.



Hubble imaged the mass of stray star clusters

Located more than 300 million light years from Earth in the constellation Coma Berenices, the Coma Cluster is one of the first places where scientists found evidence of dark matter, an invisible form of mass that can only be detected by the gravitational effects it has on its visible surroundings.

"Because globular clusters are much smaller than entire galaxies - and much more abundant - they are a much better tracer of how the fabric of space is distorted by the Coma Cluster's gravity," NASA explains.

Astronomers think that the wandering star clusters once belonged to galaxies in the Coma Cluster but were "orphaned from their home galaxy due to galaxy near-collisions inside the traffic-jammed cluster," NASA officials said. Hubble imagery has revealed that some of these outcast star clusters line up in "bridge-like patterns", which NASA officials said is "telltale evidence for interactions between galaxies where they gravitationally tug on each other - like pulling taffy".

Drug-resistant bacteria found in space toilets

The strain, known as Enterobacter bugandensis, was also recently discovered in three hospitals

Words by **Nola Taylor Redd**

NASA has discovered four previously unknown strains of antibiotic-resistant bacteria lurking in the loos aboard the ISS. A team led by scientists at NASA's Jet Propulsion Laboratory (JPL) in California analysed several bacterial samples collected from the ISS in 2015.

Researchers identified five previously unknown strains of Enterobacter bacteria - a genus with high resistance to antibiotics that often infects hospital patients who have compromised immune systems. "To show which species of the bacteria were present on the ISS we used various methods to characterise their genomes in detail," study co-author Kasthuri Venkateswaran, a senior research scientist at the JPL Biotechnology and Planetary Protection Group, said in a statement. "We revealed that genomes of the five ISS Enterobacter strains were genetically most similar to three strains newly found on Earth."

The team compared the DNA of the newfound ISS bacteria to that of more than 1,200 Enterobacter strains previously collected on Earth. The researchers concluded that the newfound strains most closely resemble the species Enterobacter bugandensis. This type of bacteria was recently discovered in three hospitals on Earth where it showed an ability to cause disease in humans and to resist multiple antibiotics.

The bacteria pose no threat to the current crew of the ISS

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UNT FOR
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Could this hidden planet really exist? All About Space meets the scientists who could be on the trail of an undiscovered world

Reported by Jonathan O'Callaghan

Astronomers have long wondered if our Solar System could contain a missing, unseen planet. A century ago some were convinced there was a gas giant lurking in the outer reaches, before later being derided for such a suggestion when it proved false. But now momentum is building that there may be another planet that has been hidden from our view and, while we haven't found it yet, we can see its fingerprints all over the outer Solar System.

This is Planet Nine, which was first seriously proposed by astronomers Mike Brown and Konstantin Batygin from the California Institute of Technology (Caltech) in 2016. Looking at the outer Solar System they noticed something odd - namely that several objects seemed to be grouped together, as if a more distant object was shepherding them into similar orbits with its immense gravity. After eliminating other possible explanations this led them to believe there must be a planet far beyond the orbit of Neptune: a real ninth planet after Pluto's demotion to dwarf planet.

"This world is the ninth true planet of our Solar System," Batygin tells **All About Space**. "We have never seen it directly, but we know it's there because of the gravitational signatures that it provides in the Solar System."

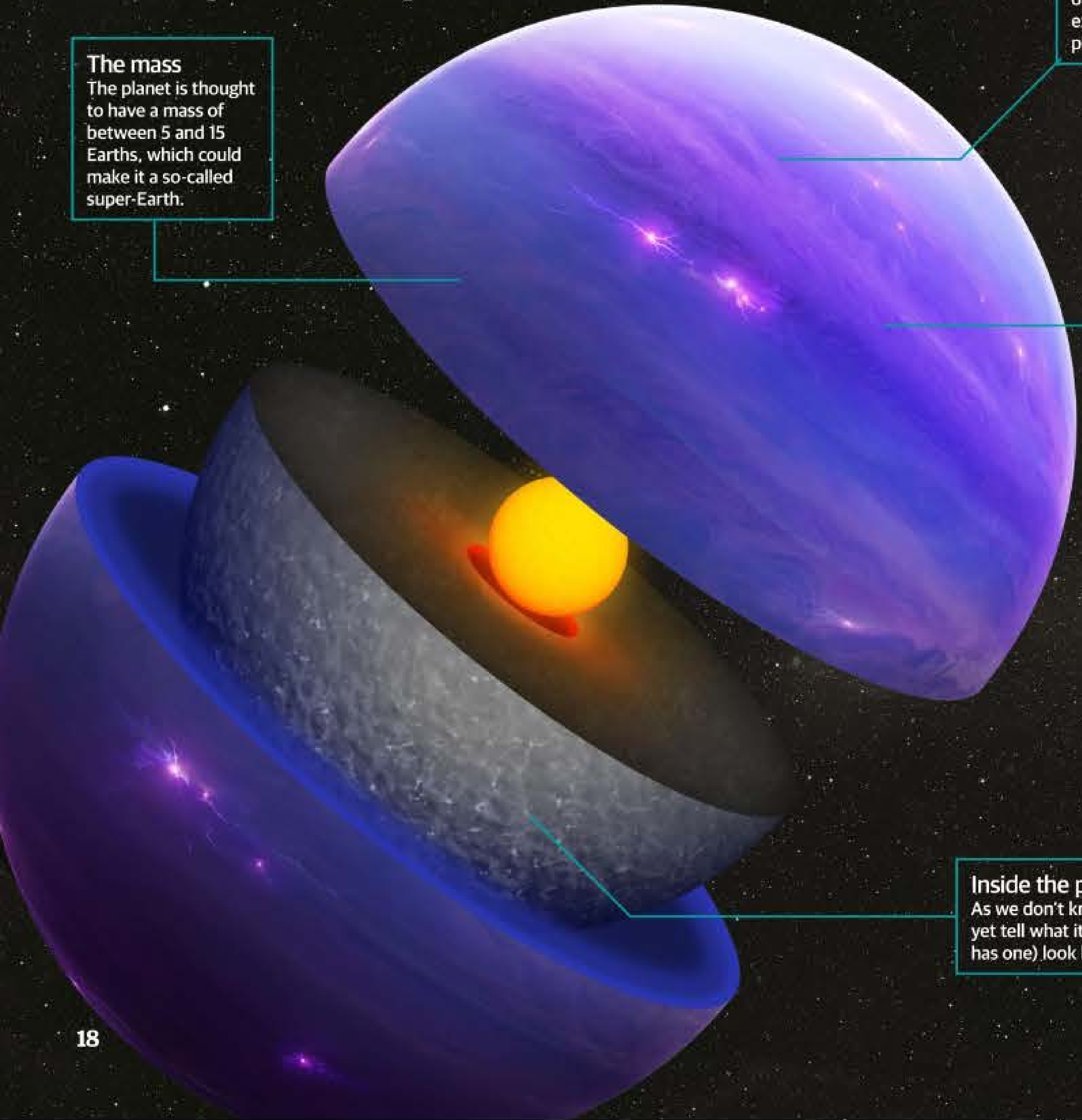
This is not the first time a planet beyond Neptune has been proposed. In 1906 US astronomer Percival Lowell was convinced there was a large planet hiding out there owing to Uranus appearing to orbit off course. He dubbed it Planet X - with 'X' referring to being unknown, rather than 'ten', as only eight planets were then known. So convinced was he that he founded the Lowell Observatory in Arizona to hunt for it.

The search for this Planet X was unsuccessful, but the Lowell Observatory did accidentally redefine the entire Solar System. In 1930 a young US astronomer called Clyde Tombaugh used the telescope to discover Pluto. At the time this sparked intense interest that this might be Planet X, but it was later found to be a small world roughly one-fifth the size of Earth, not nearly large enough to explain the orbit of Uranus.

The original Planet X was consigned to the bin, and the theory is now often scorned at, which might be why the idea of Planet Nine is so controversial. Batygin is pretty confident things will be different this time, however. "If you go back through the history of astronomy, the number of times that a trans-Neptunian planet [one beyond the orbit of Neptune] has been proposed is quite astonishing," he says. "The difference is that this

What could this other world be made of?

Here's what we know and don't know about the potential ninth planet



The mass
The planet is thought to have a mass of between 5 and 15 Earths, which could make it a so-called super-Earth.

Cold as ice
Being located beyond the orbit of Neptune, it's likely to be extremely cold - any water the planet has will be frozen as ice.

On the surface
If the planet is smaller than 1.6 Earth radii it might have a rocky surface. If it's larger, it could be more similar to a gas giant.

Inside the planet
As we don't know the planet's radius, we can't yet tell what its core, mantle or atmosphere (if it has one) look like.

time I think we're right."

If they are right, here's what we know so far. Planet Nine is estimated to be about 5- to 15-times the mass of Earth, although we don't know its radius. Its eccentric 20,000-year-long orbit around the Sun may take it anywhere from as close as 200-times the Earth-Sun distance (200 Astronomical Units, or AU) to the Sun, and up to 1,200 AU away. Such a mass has earned the planet the moniker of super-Earth, a potentially large, rocky planet up to four-times the radius of Earth. But it could also be a mini-Neptune, a gas planet somewhat smaller than Uranus and Neptune.

While we can infer the existence of Planet Nine in the outer Solar System we can't yet see it, because if it's there it's extremely distant and faint. But astronomers are trying in earnest to find it as we speak. A number of surveys around the world, and more coming online in the future, are scouring the sky to look for any sign of a planet orbiting on its predicted path. And in doing so they are also finding other objects that lend further evidence that Planet Nine exists.

So far about a dozen such objects have been discovered, each clustered on a similar path on the same side of the Sun, including the possible dwarf planet Sedna found in 2003 that takes more than 11,000 years to orbit. The most recent was 2015 TG387, more colloquially known as 'The Goblin', which was first spotted in October 2015 and

Above: A passing star could also explain the orbits of the inner Oort Cloud objects

Right: The Blanco Telescope has been instrumental in the search for Planet Nine

"We have never seen it directly, but we know it's there because of the gravitational signatures" **Konstantin Batygin**

© T.A. Rector (University of Alaska Anchorage) and H. Schweiker (WIYN and NOAO/AURA/NSF), Tobias Roetsch, David walker

announced in October 2018 by Scott Sheppard from the Carnegie Institution for Science and his colleagues. Thought to be a dwarf planet about 300-kilometres (186-miles) across and orbiting the Sun every 40,000 years, The Goblin is yet another piece in the puzzle that Planet Nine exists.

"The Goblin continues the trend seen in the past for this planet that we think is out there," Sheppard tells **All About Space**. "If it matches our predictions, then The Goblin is stable to its orbit, and it kind of dances with the planet."

Objects like The Goblin are given a specific moniker: inner Oort Cloud objects. They are found in a region between the Kuiper Belt and the Oort Cloud, the former extending from 30 to 55 AU and the latter anywhere from 2,000 to 200,000. This region, notes Sheppard, is a 'no man's land' where the objects are too far away to be affected by the eight known planets, but still bound to the Sun and oblivious to outside forces like other stars or the supermassive black hole at the centre of our galaxy.

Only a dozen such objects have been found so far, but the number could be higher. Much, much higher. It's estimated that thousands of these objects larger than 50 kilometres (30 miles) in size, or even perhaps millions, could be in orbit around the Sun. As their orbits are very elongated, however, they spend most of their time far away, only brightening and becoming visible when they approach the Sun. "We're just seeing the tip of the iceberg," says Sheppard.

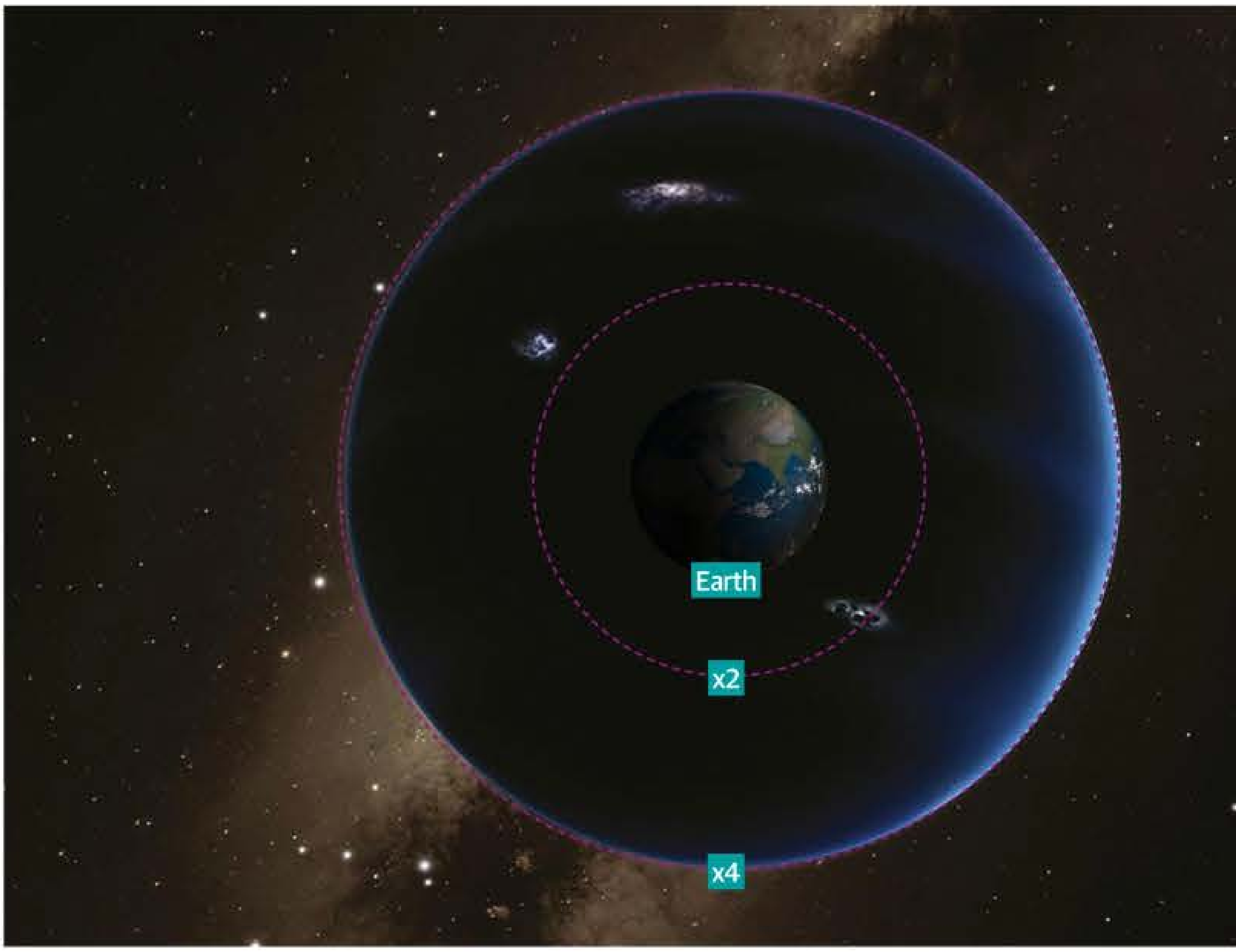
Not everyone is convinced these objects are proof of another planet, however. There are other explanations that, with a bit of fiddling, can explain how they cluster together, and the theory of Planet Nine is anything but widely accepted just yet. "You can do this with a flyby of another star or a brown dwarf, a massive object early in the Solar System's history," says Michele Bannister from Queen's University Belfast. "Potentially [there are] also some physical processes that involve how the objects interact with the inner Oort Cloud and the tide of the galaxy. [Or] Neptune [could] perturb some of these objects over hundreds of millions of years."

In mid-2018 a team led by Ann-Marie Madigan from the University of Colorado, Boulder proposed

Above: Sedna was the first body found in the Solar System's "no man's land"

Below: If it exists, Planet Nine could be 2- to 4-times the size of Earth

> "The main goal right now is finding more of the smaller objects that can lead us to the bigger one" **Scott Sheppard**



Clues to another world's existence

Clustering of objects

A dozen objects in the outer Solar System seem to be clustered together, with their closest points to the Sun all being fairly similar. This suggests there is a large unseen mass - a planet - shepherding their orbits.

The same side

Not only do those 12 objects have a similar perihelion, but they are also all grouped on one side of the Sun. Again, this suggests there is something out there pulling them in that direction.

The wrong way

Some objects in the outer Solar System appear to be orbiting in the opposite direction to everything else, perhaps being pulled into these extremely elliptical orbits by Planet Nine.

The missing super-Earth

Many other planetary systems we've found in our galaxy contain a super-Earth. Could Planet Nine be the missing planet from our Solar System that's common almost everywhere else?

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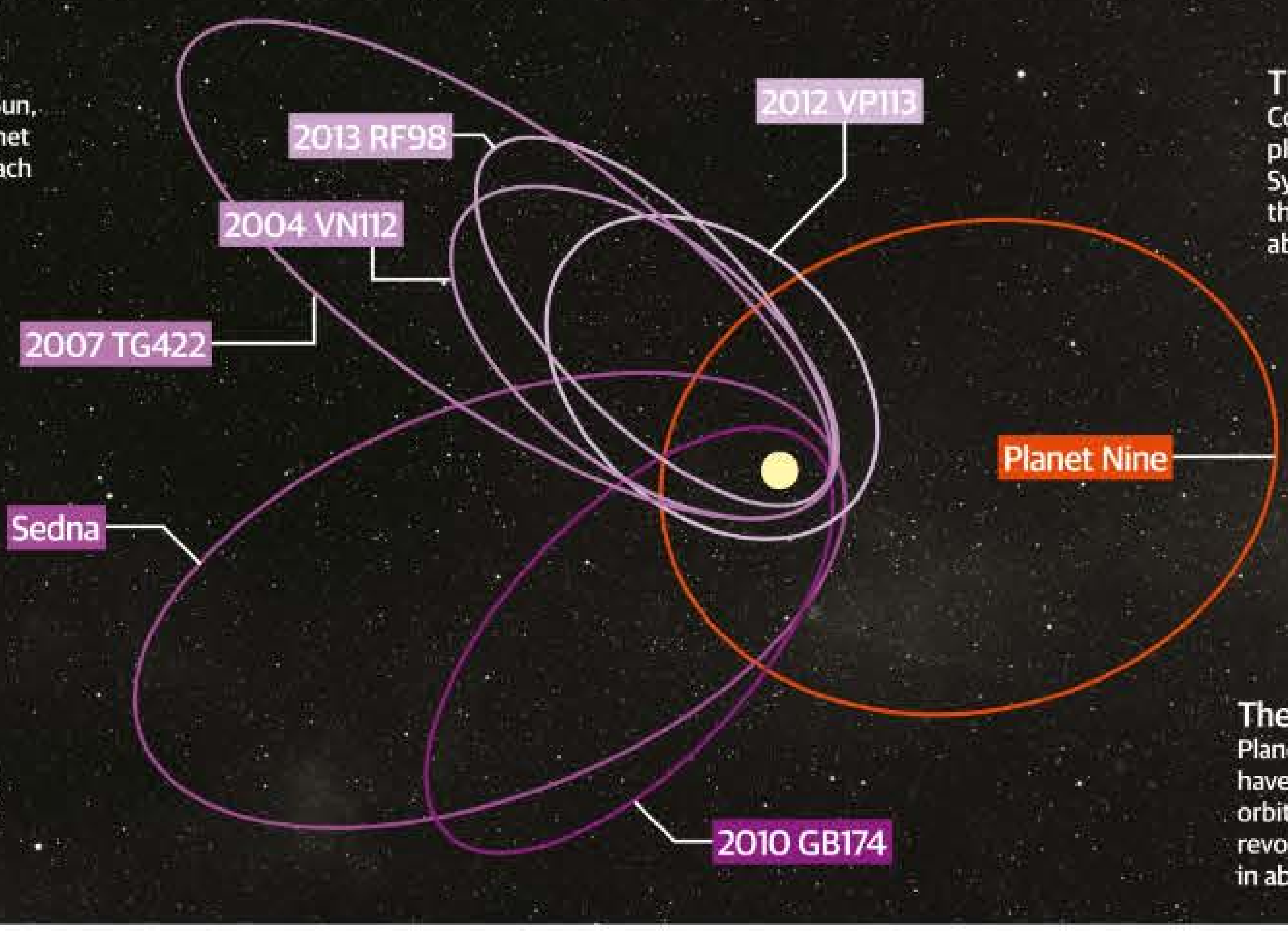
Planet Nine's orbital path

How we think this world dances around the Sun

Closest point
At its closest point to the Sun, known as a perihelion, Planet Nine is predicted to approach to about 200 AU away.

The next-nearest planet
Neptune's orbit only takes it out to about 30 AU, more than six-times less than the perihelion of Planet Nine.

The inclination
Compared to the other planets of the Solar System Planet Nine is thought to be inclined by about 30 degrees.



Farthest point
Planet Nine's orbit is thought to extend out to a distance of up to 1,200 AU from the Sun into the far outer Solar System.

The shape of its orbit
Planet Nine is thought to have a highly eccentric orbit, completing one revolution around the Sun in about 20,000 years.

an additional possibility. They say the natural jostling of the dozen inner Oort Cloud bodies found so far, and space debris in the outer Solar System, could explain their orbits. The collective gravity of the bodies, they say, could provide an answer as to why they clustered together.

The main issue is that these dozen bodies we have discovered so far shouldn't really be there. "They are small bodies in the outer Solar System that shouldn't exist," says Megan Schwamb from the Gemini Observatory in Hawaii. And that has led to the suggestion of Planet Nine, but it doesn't mean that is the only explanation. "The same evidence for is also the same evidence against," says Schwamb. "You could have formed these objects detached from Neptune in a stellar cluster. Early on in the Sun's history many stars coming within 500 to 1,000 AU would have stirred up objects and would have been able to detach them from the outer Solar System and put them in these eccentric orbits. Other options are a single star passing by, or rogue planets leaving the Solar System."

Getting to the answer will be no mean feat, but answers may be forthcoming rather soon. At the moment our observations and data for this region of the Solar System come mostly from two telescopes, the Subaru Telescope in Hawaii for the northern sky, and the Blanco Telescope in Chile for the southern sky. Observations were especially helped by the installation of the Dark Energy Camera (DECam) on the Blanco Telescope in 2012. "Up until 2012 it was like looking through a straw," says Sheppard. "In 2012 the game changed and allowed the floodgates to open for this kind of research." But even together these two telescopes can see only a small patch of the sky, with about 20 per cent of the sky observed to date, and as the inner Oort Cloud objects are so far away and so faint, they're extremely hard to see.

The game is going to change again though in 2022, when a new telescope called the Large Synoptic Survey Telescope (LSST) comes online in Chile. Although predominantly designed to find near-Earth asteroids, the LSST will also be able to find more objects in the outer Solar System, covering about 70 per cent of the sky in total. And if there are thousands or millions of objects out there as thought, then there could be a whole swathe of worlds – and possibly more evidence for or against

The Large Synoptic Survey Telescope could narrow down Planet Nine's location from 2022

Planet Nine - awaiting our discovery. "Though we want to find the planet, the main goal right now is finding more of the smaller objects that can lead us to the bigger one," says Sheppard. "If we can double that number, we can start limiting where the planet can be."

After that the next big step will be actually seeing Planet Nine. Scientists are already poring through images of the outer Solar System hoping to spot its faint glint but, without knowing its exact location, such efforts are extremely difficult. If it were at its point nearest the Sun right now it would likely already have been spotted owing to its brightness, so if it exists it is more likely much farther out in the Solar System near the outer point of its orbit, known as aphelion, where it also moves at its slowest speed. So far, mostly using the Subaru Telescope, efforts to find the planet have been unsuccessful, but the hunt continues.

Until then, Planet Nine will continue to be hotly contested. While some are convinced it exists, others are not quite ready to throw their hat in the ring just yet, with memories of Planet X and other faux worlds no doubt fresh in the mind.

"I'm agnostic about whether it's a planet or not," notes Schwamb, while Sheppard says he is "80 to 85 per cent sure" it exists. But if all the stars - or should we say, inner Oort Cloud objects - align, then perhaps there really is a missing super-Earth hiding. "I don't think we're going to find it next week, but at the same time I don't think it's going to take 20 years to find this thing," Batygin says resolutely.

Above: Planet Nine could give a new insight into how our Solar System formed

Below: Scientists are using the Subaru Telescope in Hawaii to hunt for Planet Nine

Debate: Is it likely that another planet exists?

Scientists are conflicted about the existence of a ninth Solar System member

Yes

If another world is not there you need other theories to explain each of the anomalous patterns we see. You need a theory to explain why the orbits are aligned together, a theory to explain why objects are out of the reach of Neptune and another to explain why some orbits get flipped upside down. Another planet explains all of these anomalies consistently.

Konstantin Batygin, California Institute of Technology

No

A small group of us are working on an alternative hypothesis which involves the collective gravity of minor planets. These minor planets orbit so far away from the Sun and the major planets that the weak gravity acting between them can build up slowly over time and come to dominate their dynamical evolution. They can rearrange their own orbits into a distribution similar to what we observe in the outer Solar System without the need for another planet. This explanation predicts that there is a disc of minor planets more massive than the Kuiper Belt awaiting discovery at hundreds of AU.

Ann-Marie Madigan, University of Colorado, Boulder

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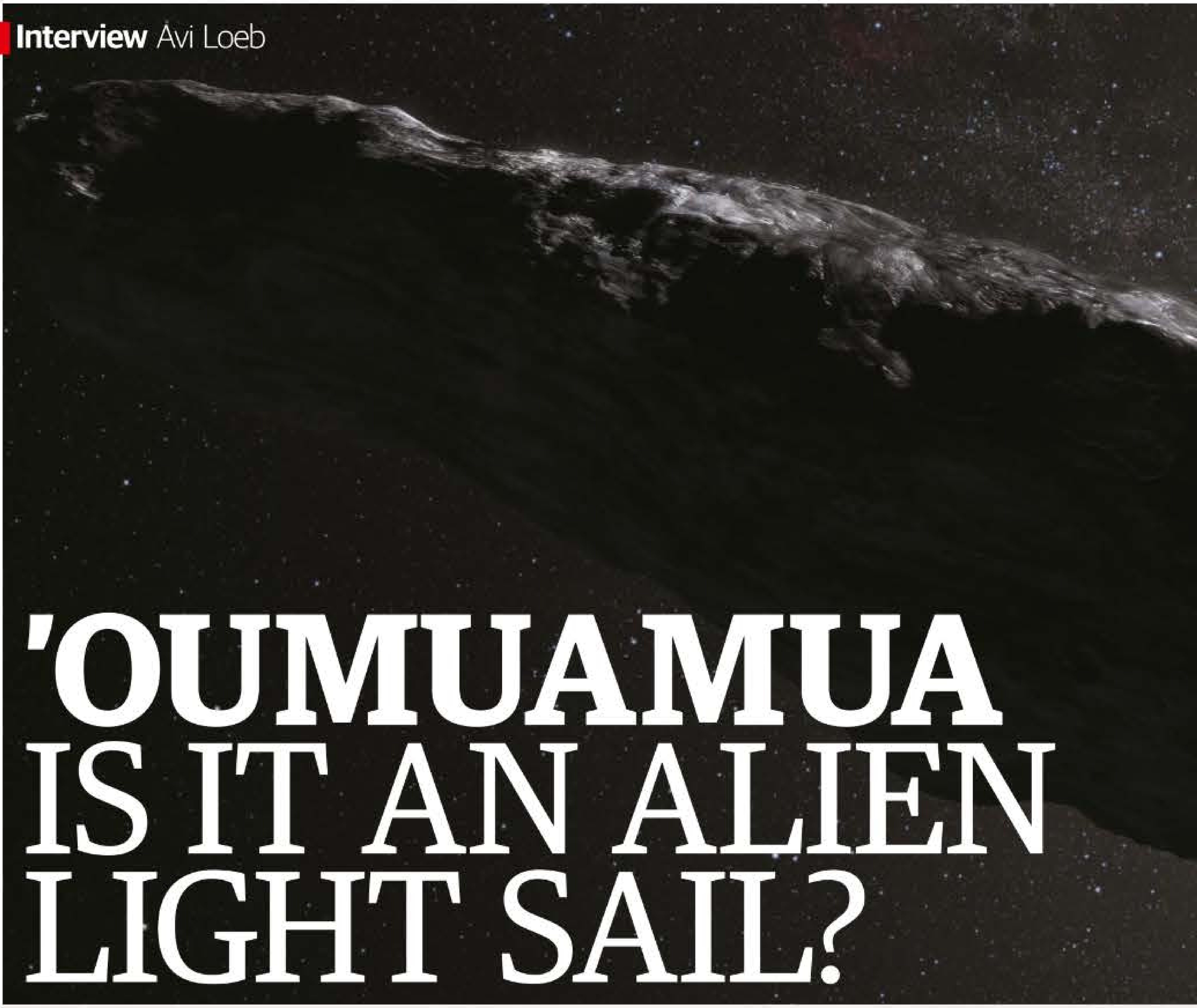

'OUMUAMUA IS IT AN ALIEN LIGHT SAIL?

Professor Avi Loeb discusses the controversy of ruling out every possible scenario in uncovering the origin of an extraterrestrial object that was spotted in our Solar System in 2017 - even the chance it could be a message in a bottle from an alien civilisation

For our readers, please could you provide a bit of background on 'Oumuamua?

It was discovered just a year ago, 19 October 2017, when it passed close to the Earth. It's a relatively small object, tens to hundreds of metres. We don't exactly know the dimensions because we don't have any images of it. It is the first interstellar object to have been discovered in the Solar System in the sense that it is unbound to the Sun, and it is similar to having a guest to dinner that comes from another country. By 'speaking' or examining this guest you can learn about the culture of their country without having to visit and pay an aeroplane ticket.

This object, surprisingly, was very weird. It's nothing that we have seen before in the sense that its shape is very extreme. What we see is the reflected sunlight, and the brightness of the object varies by a factor of ten, which implies that it is at least five- to ten-times longer than it is wide, but we don't know exactly how it looks. Everyone's seen these images of the cigar shape, but we don't know [if this is true]; this is just an artist's impression. It could also be a pancake. Observations of this object with NASA's Spitzer Space Telescope indicate that it is a very good reflector. It's relatively cold and does not absorb much sunlight.

People thought of it as an asteroid, and it doesn't fit the pattern of our Solar System's asteroids. In the Solar System the asteroids are at most three-times longer than they are wide, but then even if you say, "Okay, well, its shape is unusual by chance. It's an outlier." Even then most of the asteroids that you can imagine being ejected would come from the outer parts, where their ejection speeds would be relatively small.

Is finding an object like this quite common?

Another thing that is very unusual, we wouldn't expect this object to be found in the first place because I actually wrote a paper about a decade ago predicting how many rocks from outside the Solar System we should see. The expected abundance is about 100 to 100 million-times smaller than needed to explain 'Oumuamua, and so it tells you that is very abundant.

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> "It's nothing that we have seen before in the sense that its shape is very extreme"

INTERVIEW BIO

Professor Abraham (Avi) Loeb

Avi Loeb is an Israeli-American theoretical physicist and the Frank B. Baird Jr. Professor of Science at Harvard University, Cambridge, Massachusetts, United States. He is involved in many other astronomy organisations as well, including being chair of Harvard's Department of Astronomy, founding director of the Black Hole Initiative and chair of the Advisory Committee for the Breakthrough Starshot Initiative, to name a few.

Loeb's work in theoretical physics has led him to study many aspects of space, from exoplanets to black holes. In 2012, *Time* magazine also selected Loeb as one of the 25 most influential people in space science.

So then you need to assume that other stars are producing something weird much more often than we expect the Sun to do. You need something like a thousand trillion objects being ejected per star during its lifetime.

So, in addition to that, the most intriguing part of it is that it moves on a trajectory that deviates from one that is shaped just by the Sun's gravity. Now that is usually attributed to outgassing - in other words, ice evaporating on a comet's surface to give a rocket effect that pushes it in the other direction - and the problem with that is we don't see any evidence for gas or dust coming off this object, so there is no cometary tail. On top of that, if there was it would have also created a change in the spin of the object, and we don't see that.

What about 'Oumuamua's orbit is very unusual?
It's moving mostly due to the Sun's gravity… mostly. But there is a correction to the orbit. We can measure the orbit extremely precisely and we know the mass of the Sun, so Newton's law of gravity tells us exactly how the object should move. But there seems to be a deviation with the orbit.

The force that needs to act [on 'Oumuamua] is a small fraction of the force exerted by the Sun, but in fact it is very big because in order to generate this deviation via a cometary tail, you need to evaporate a major fraction of the mass. So it is not easy to get these levels of deviation, and the propelling mechanism isn't being seen. This looked very weird to me.

What was the reaction to your scientific paper suggesting that this could be an artificial object made by an extraterrestrial civilisation?
So I wrote this paper, which was refereed in the standard procedure. It was accepted for publication within three days, which I found extremely unusual, but it's a prestigious journal called the Astrophysical Journal Letters. But I don't understand why some people have an issue with it. In fact, the reporting in the news appeared after the paper had already been accepted, and some people didn't know it was and said, "Oh, the people weren't

The Large Synoptic Survey Telescope will carry out a deep, ten-year imaging survey

Loeb urges humanity to believe we are not alone and continue the search for extraterrestrial intelligent life

refereed... it's just speculation." But it went through the standard procedure!

Here is the standard procedure in science: there is data. You look at the data. If there is an anomaly, you are trying to explain this anomaly. In this case there is an anomaly; this deviation. So people try and explain it in terms of cometary outgassing, but there is no cometary outgassing as far as we can tell. So what do you do?

You have two options. Either to say the data is wrong, or to say let's look for another explanation, which is what our paper does. Our paper says maybe it's the force from the radiation of the Sun that is pushing on it, and that's it. So we wrote the paper; we put it out.

This is prejudice if you dismiss a possibility. I was shocked at first to see so much reaction from the press. That's another thing. I just followed the logic of Sherlock Holmes, basically saying when you've excluded the impossible, whatever remains, however improbable, must be the truth. I don't have a prejudice. I just want to find the explanation for this extra push, and that's what we put in the paper.

What's behind your creative thinking in this regard?

The privilege of being a scientist is that we can maintain our childhood curiosity. We don't need to pretend that we know something we don't. Children learn about the world by asking questions and by being innocent, but not pretending. When they become adults they start pretending they know more, they start trying to look respectable, they start to pay attention to titles and I hate that. Even though I have a lot of titles. But I just hate to give up on this privilege of being a scientist and being straightforward and honest about what you know and what you don't know.

It's quite possible, and quite likely to some people, that this will be ruled out when we look at the next object. Let's leave it on the table and then rule it out. Now if this is ruled out, something else must be ruled in, and the fact that this object is weird implies that, in respective, we will learn something new. We will learn that the galaxy produces weird objects in some environments that we don't know in a number that is much larger than we expected.

It's sort of like going to the beach and looking at seashells and suddenly seeing a plastic bottle and you say, "What's that? Where did it come from? Could it be artificially made?"

Do you think we are alone in the universe?

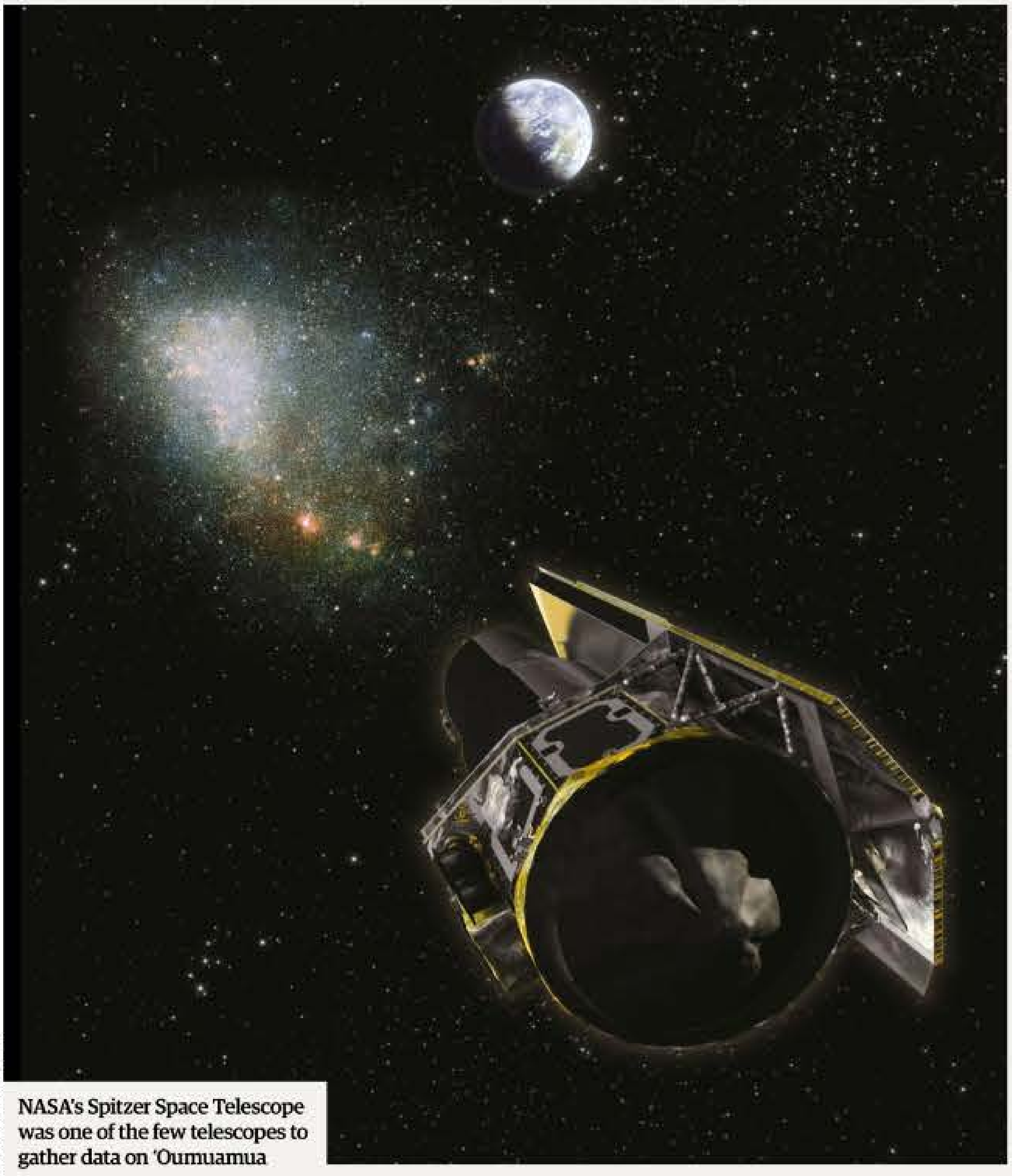
I don't have a prejudice that we are alone, because a quarter of all the stars in the universe have a planet in the habitable zone where liquid water can exist on the surface and the chemistry of life, as we know it, may be happening elsewhere. So why should we be so arrogant as to say that we are the only civilisation out there?

I think out of modesty, just modesty, we should all think we are not alone and then search. I'm not saying that we have any conclusive evidence at the moment, but we should just search for it and not have a prejudice against it like some people's reactions, even though they have no evidence. That's very bad; it's similar to what the Church did when Galileo was arguing that the Earth moved around the Sun.

So what about 'Oumuamua makes you think it could be an artificial light sail?

We tried to explain the extra push that it feels by saying that the light from the Sun is pushing on it. In order for that to be effective it needs to be very thin, less than a millimetre. It appears to have a large area-to-mass ratio. Therefore, based on the amount of sunlight that we see reflected from it, it has to be at least 20 metres (65 feet) in size, and that sounded like a light sail. This is technology our civilisation is currently developing for space exploration and I actually chair the Advisory Committee for the Breakthrough Starshot Initiative.

I would admit that my imagination is limited to what I know and that's usually the case for everyone. The fact that I'm involved in [the development of] this technology inspired me to think in this direction, but it is quite possible that other civilisations have mastered this technology. This could be a message-in-a-bottle situation, which means instead of detecting a signal, which people



NASA's Spitzer Space Telescope was one of the few telescopes to gather data on 'Oumuamua

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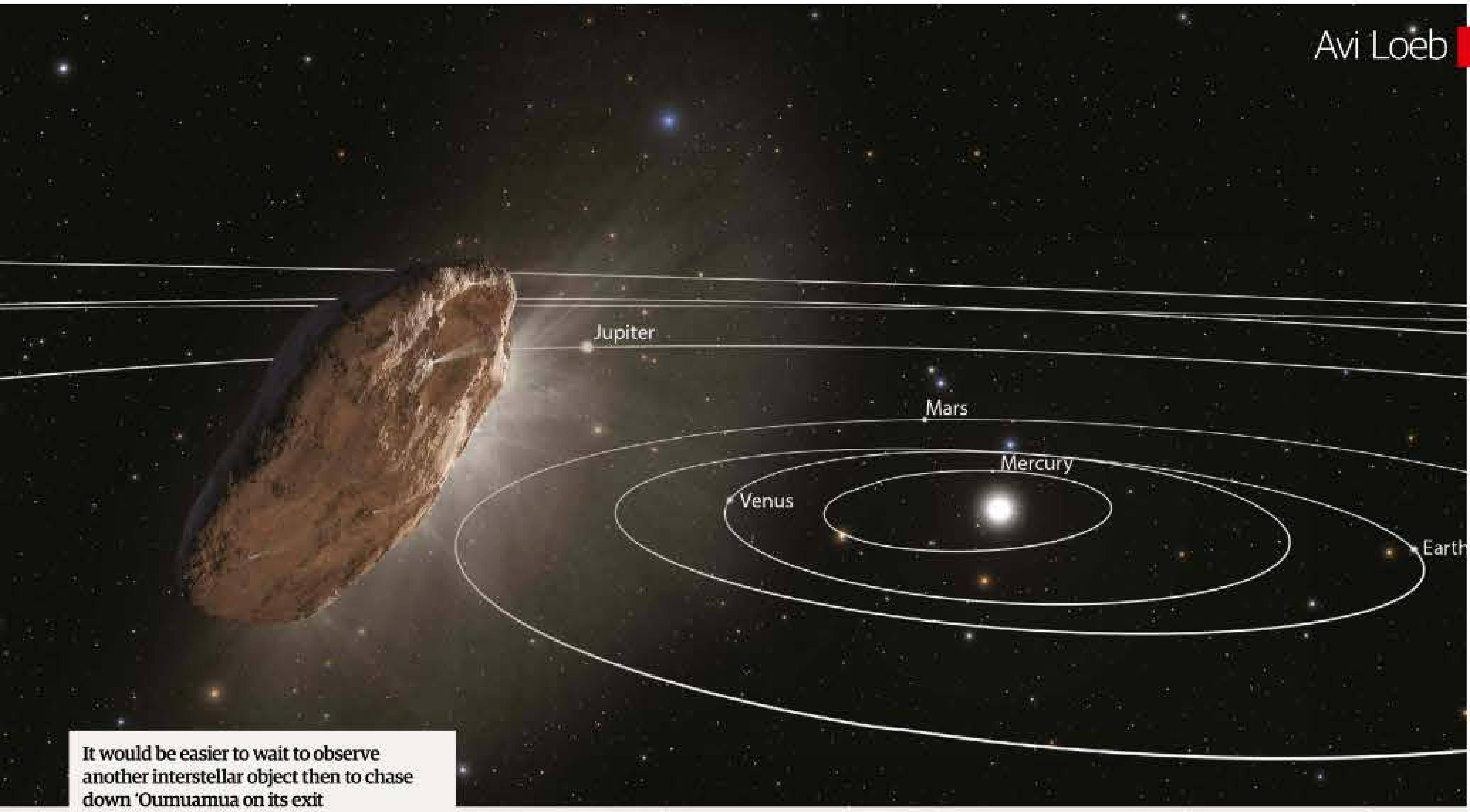


It would be easier to wait to observe another interstellar object then to chase down 'Oumuamua on its exit

"So why should we be so arrogant as to say that we are the only civilisation out there?"

have thought about in the past with detecting a electromagnetic signal, we would detect an object.

Playing devil's advocate to your own statement, what arguments are there against the idea of it being an artificial object?
That's the point. Other than cometary outgassing nobody has a suggestion for what could produce this extra force. What I've heard is people saying maybe the observational paper is wrong, but the observational paper has a lot of data points and it takes the statistical significance of 30 standard deviations. Usually for a signal to be significant you need three or five; it makes researchers very happy if they have five standard deviation signals. This one had 30, so it's clear beyond a reasonable doubt that - in the eyes of the observers that did the observing - there is this anomaly that it gets an extra push. The pressure is on what produces it.

If you do the numbers you work out that a significant fraction of the mass of this object will need to evaporate to push it enough. Yet it needs to be pure material that does not appear in dust, because cometary tails are usually apparent because of the dust. More over, people have looked for gases of various types and didn't see that. So to me, when you don't see something it doesn't exist. If it's not a comet, then what is it?

If this were an alien space probe, where do you think its home system would be?
We can't track it back to a star because that would imply that it's ejected from a particular star at very high speeds, which would be unlikely. Most of these objects in a stellar system are in the Oort Cloud and they move at a fraction of a kilometre per second and you need - for the typical speed of a object at rest - you need to be kicked by something in the order of 20 kilometres per second (45,000 miles per hour). This would imply that it's ejected from the inner part of the stellar system, roughly where Jupiter is [compared to the Solar System]. But then there are fewer objects there.

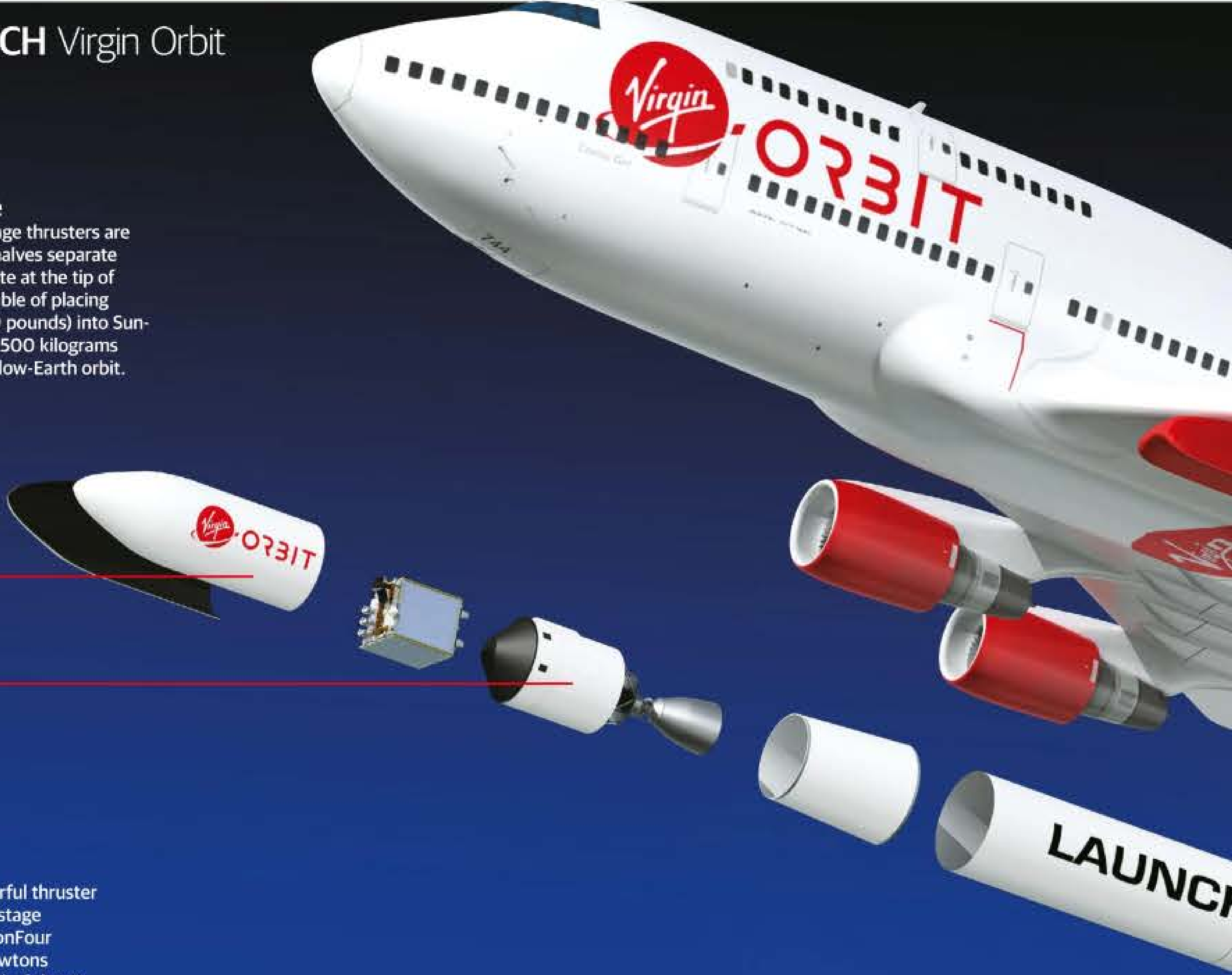
The number game appears a bit implausible given what we know about the Solar System. But we don't know which star it came from. Maybe it ['Oumuamua] took 100 thousand years to come to the nearest star. Then suppose it's not the nearest star, it's another one a million years away. Then you need to know the motions of all the stars and where they were a million years ago and figure that out. We cant reliably go back a million years and figure out exactly where it came from.

Are extra efforts being made to look for more objects that originate from beyond the confines of our Solar System?
Yes, that's the key. So you can imagine two ways of getting more data. One is to chase this guy, but the problem is current chemical rockets can't do it, and the second is look for another one, and that will be possible in the future. With this existing survey [the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) in Hawaii] we discovered it, so maybe we just need to wait a few years for the next one. However, in a few years there will be a survey that is much more sensitive called the Large Synoptic Survey Telescope and that will be an excellent survey for finding additional ones.

If we find more of the same then we will have all our telescopes ready and everyone will be alert. That's an important point in my paper that it alerts the community to the importance of finding more data on such things. When the next one comes along everyone will be motivated to rule out this or that, and so we will get much more information. There is nothing better to a scientist than more information, unlike a politician. In politics, sometimes less information is better because you can justify your views, but in science the more information you have the better. The problem is we don't have enough.

Would it be possible to send a spacecraft to such an object?
Yes. You could even meet it halfway if it moves at the same rate as 'Oumuamua. What you don't want to do is wait until it runs away from you, because then it's too late.

Cometary outgassing is one of the explanations for the unusual push on 'Oumuamua



Payload module
Once the second stage thrusters are fired the clamshell halves separate to release the satellite at the tip of the rocket. It is capable of placing 300 kilograms (660 pounds) into Sun-sychronous orbit or 500 kilograms (1,100 pounds) into low-Earth orbit.

Second stage
The final, less powerful thruster will fire the second stage to orbit, with NewtonFour delivering 22 kilonewtons (4,900 pound-force) of thrust.

VIRGIN ORBIT TO LAUNCH SATELLITES

Cosmic Girl and LauncherOne will combine to become a big player in commercial spaceflight

In the expanding race for commercial space flight it appears that Elon Musk's SpaceX is leading with its contracts with NASA to deliver cargo to the International Space Station, as well as delivering other organisations' satellites to low-Earth orbit. One of the other runners includes British billionaire Sir Richard Branson, owner of both Virgin Galactic, which is focused on spaceflight and space tourism, and Virgin Orbit, which focuses on delivering satellites into orbit, as part of the Virgin Group.

As of 26 October 2018, Branson has flaunted the craft that will make Virgin Orbit a major runner in satellite delivery, in Branson's words, "connecting the world". There has been much optimism over the recent unveiling of the dynamic duo that is the LauncherOne rocket and its carrier plane, named Cosmic Girl, which is a modified former-Boeing 747-400 aircraft. LauncherOne is an idea that first came into existence in 2007. However, the original concept was shelved in 2015 when Virgin Orbit decided to go for a larger rocket with a bigger payload capability, upgrading the original 200 kilograms (440 pounds) to low-Earth orbit to 300 kilograms (660 pounds) to a Sun-synchronous orbit.

Branson claims that Cosmic Girl and LauncherOne will deploy satellites into orbit in early 2019. Cosmic

First stage
Once reaching a 9,100-metre (30,000-foot) altitude the NewtonThree rocket will fire its pump-fed LOX/RP-1 liquid rocket engine. The NewtonThree engine produces 330 kilonewtons (74,000 pound-force) of thrust.

© Adrian Mann

Girl will make the initial 9,100-metre (30,000-foot) climb into the atmosphere before LauncherOne fires its thrusters to drop off satellites, travelling at speeds of 28,000 kilometres (17,500 miles) per hour. In a recent blog post Branson explained that "the team were carrying out the integration check of the rocket with Cosmic Girl to verify mechanical, electrical, software and dynamics all work together for the first time".

LauncherOne will be able to carry payloads "that could be as small as a loaf of bread and as large as a household fridge". It uses two Virgin-designed engine stages: NewtonThree produces 330 kilonewtons (74,000 pound-force) of thrust while NewtonFour will provide a smaller 22 kilonewtons (4,900 pound-force). Early into the burn of the second stage the payload at the tip will jettison its clamshell and release the satellite.

The launch vehicle can fly for thousands of miles in any direction with as little as 24 hours notice, whereas at the moment satellite launches from the ground will usually have to wait between 18 and 24 months. This innovative thinking will allow for more frequent and affordable launches, and it will become apparent in the following months just how much of a player Virgin will be in the game of commercial space.

CHASING NORTHER

All About Space heads north to seek out nature's greatest light show

If there's one thing on the bucket list for most, it's seeing the northern lights. Also referred to as the aurora borealis, it instills a sense of wonder in the minds of many. Its characteristic and stunning green glow as it weaves its way through a sky above snow-capped mountains is a scene that many have admired in a photograph. Not many can say that they have had front-row seats to nature's very own light show though. This is because you have to be in the right time and in the right place to see it awaken the sky with its shimmering dance.

Keen aurora hunters often find themselves at the highest latitudes in the world. They know that the further north you go, the greater your chance of catching the northern lights. And it's true – many locations close to the North Pole, including the icy and freezing conditions of Iceland to those of Norway, are popular destinations to see the aurora borealis at its best. These regions are located within the auroral oval (right), a band where auroral activity can often be found. It is here – when luck is on their side – that observers can witness the northern lights from one night to the next, particularly during times when the Sun is at its most active.

Significant solar activity can make or break your observing experience. Our Sun and the solar wind, which our star belches out in the form of charged particles, is a key player in bringing the northern lights to life. It is these energetic particles, which are angrily blasted from our Sun as mass ejections and solar flares, which distort our planet's magnetic field.

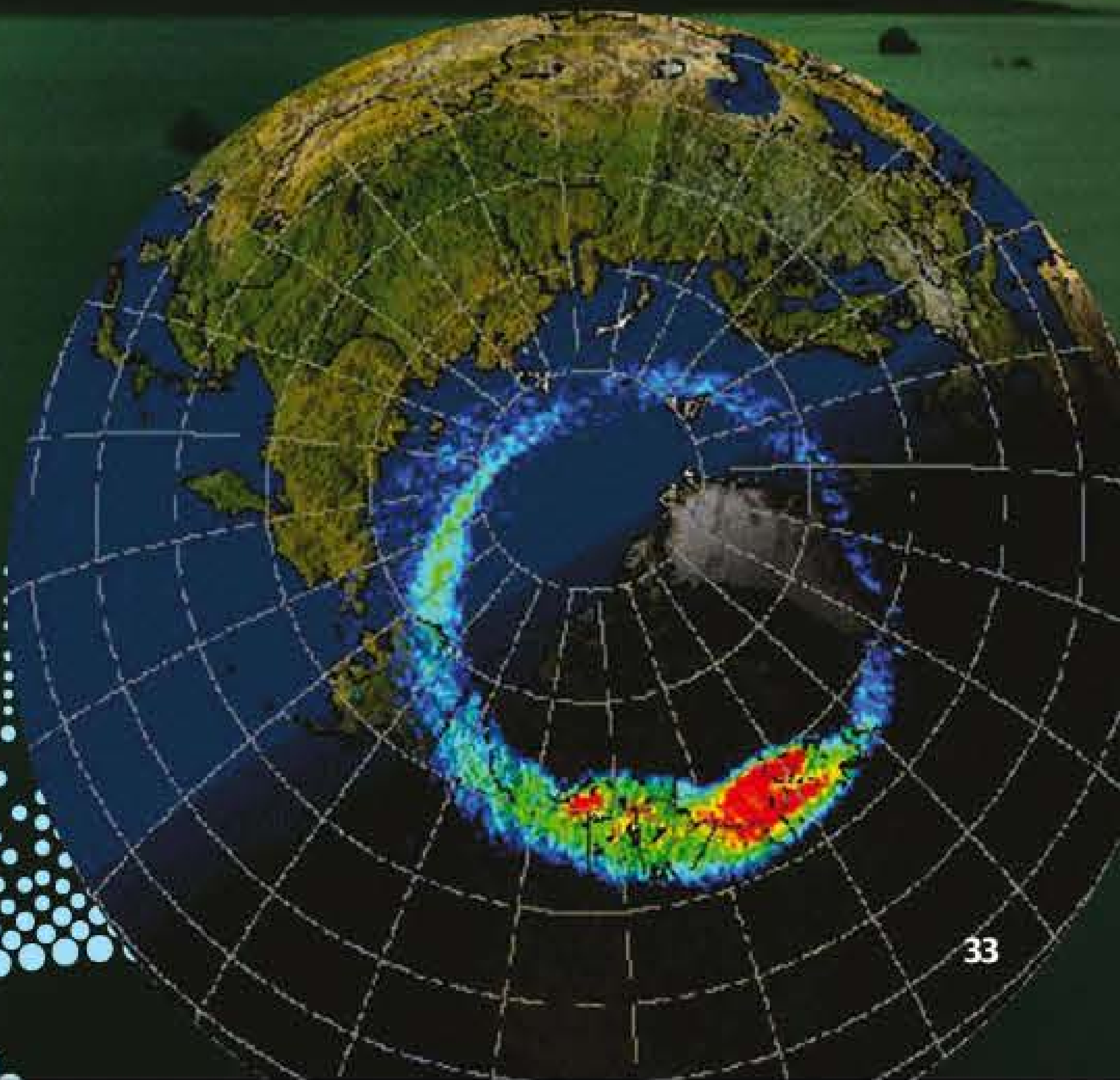
© ISSL Peerasit Chockmaneetuch; Bokasana

THE RN LIGHTS

During the interaction some particles have the opportunity to slip by the Earth's protective shield and collide with atoms in our atmosphere. A glow akin to a fluorescent tube is made, taking the form of curtains, arcs or even spirals of light: the northern lights.

Aurora borealis can take the form of many colours – anything from an eerie green through to pinks and purples. It's the oxygen in our atmosphere that's responsible for the usual greens, while blues, reds and purples signal that nitrogen has been excited.

Just how dazzling these light shows can get really depends on the strength of the solar winds. The stronger they are the less confined to the north they'll be, with observers further south having a better chance of seeing them.



Top places to see aurora borealis

Take a trip to the Arctic Circle for your best chance of catching the northern lights

Tromsø, Norway

Kiruna, Sweden

Þingvellir National Park, Iceland

Bear Lake, Alaska

Norway

The aurora borealis is at its most active between late autumn through to early spring, with many taking the opportunity to hunt for the lights at around 6:00pm to 1:00am between the equinoxes.

While you will be able to see the northern lights from any location in Norway, the best locations are above the Arctic Circle in northern Norway or the Svalbard Islands. It's said that there's no other place on Earth that offers better chances of spotting the lights since the aurora borealis belt hits Norway's Lofoten Islands, following the coast all of the way up to the North Cape.

Iceland

While you can see the northern lights from almost anywhere in the country of Iceland, a recommended spot involves you leaving the capital of Reykjavik and heading out to the plains of the Þingvellir National Park to catch nature's light show.

Your best chance of spotting the aurora borealis is during September and October or during the end of February and beginning of March. Remember that during May and all the way through to August Iceland becomes the land of the midnight Sun. That's when it's daytime all of the time, so be sure to avoid these months if you're hunting for the northern lights.

If you're feeling adventurous you can catch a domestic flight to Akureyri, a town in the northern part of the country. Here, you'll be provided with a doorway to other rural parts of Iceland and free of light pollution.

Sweden

The northern lights usually make their appearance during the winter months through late March or early April and can even be spotted as early as September in the northernmost parts of Sweden.

Abisko National Park, the village of Jukkasjärvi and the Torne Valley as well as Porjus and Laponia in Swedish Lapland are favourite locations to witness the aurora borealis. Other regions in Swedish Lapland, even those close to large towns such as Luleå, Jokkmokk, Arvidsjaur and Gällivare, offer opportunities to see the lights. If you prefer to head out into the wilderness, far from bright artificial lights, be sure to visit the Brändö forest.

Finland

In Finnish Lapland it's been estimated that you can see the northern lights roughly 200 nights a year, provided these nights are free of cloud and free of any other hindrances such as light pollution. Kakslauttanen, which is situated close to Finland's Urho Kekkonen National Park, is a natural area that's highly regarded as a very good region to spot the northern lights. In Finland your best bet of seeing aurora borealis is during late August all of the way through to April.

Northern Canada

Northern Canada provides an excellent base for aurora seekers. Yellowknife in the Northwest Territories of Canada, also known as Aurora Village, is situated directly beneath the aurora oval,

Snowy Forest, Finland

Banff National Park, Canada

Kola Peninsula, Russia

> "The northern lights usually make their appearance during the winter months through late March or early April"

meaning that it is one of the best places in the world to see the lights. Being quite a flat region, geographically speaking, Yellowknife also allows for a higher percentage of clear weather, especially in the winter.

Russia

Being so close to the Arctic Circle, Russia is another ideal location to chase the northern lights, with almost all of the northern regions of the country offering fantastic views.

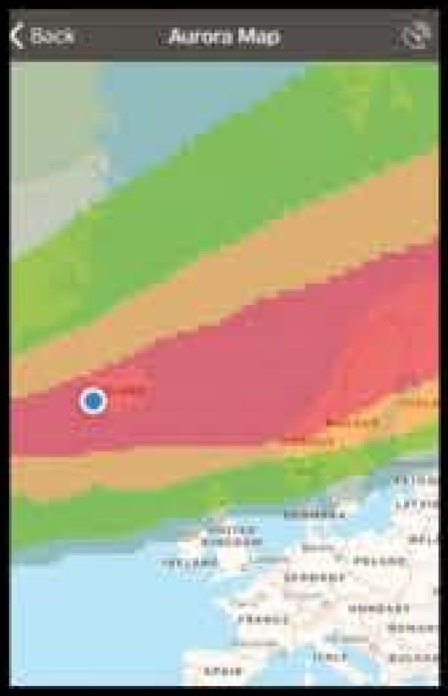
The Kola Peninsula is a favourite location during December and January where great stretches of wilderness are under pitch-black days and nights as the Sun disappears for the better part of six weeks. Around the city of Severodvinsk is also an excellent location, promising excellent auroral glows.

Alaska

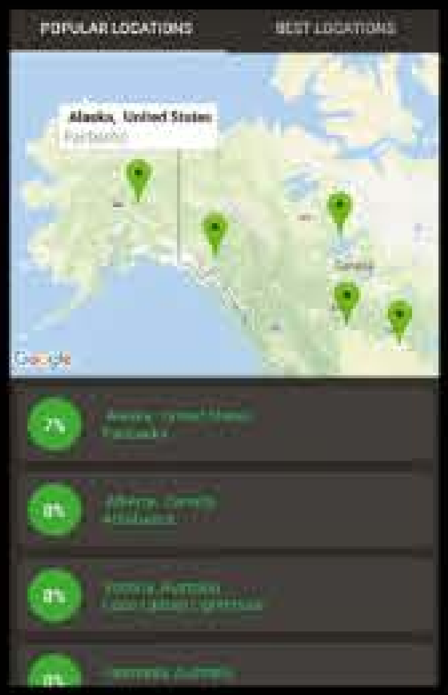
Alaska is an excellent location to watch the aurora borealis dance across the night sky, with Fairbanks, Denali and the Yukon Territory all being superb locations. It is said that if you head out to these locations during the right time of the year, you'll have around an 80 per cent chance of witnessing the northern lights.

Can I predict the aurora?

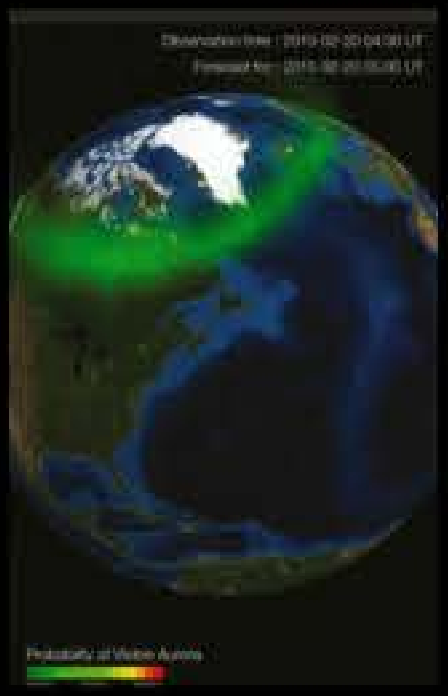
With the help of websites and apps available for iOS and Android, it is possible - albeit very roughly - to predict if you'll be treated to a display of the northern lights from your location.



My Aurora Forecast
Cost: Free
On: iOS and Android



AuroraCast
Cost: Free
On: iOS and Android



Aurora Forecast
Cost: Free
On: iOS only

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Seeing the northern lights: what to expect

Being prepared and patient is key to grabbing spectacular views of the aurora

Anyone who hasn't witnessed the northern lights already has an image in their minds of what it looks like. They picture it to be a vivid green arc or curtains of light that dominate the entirety of the Arctic sky, so bright that it reflects from the lakes and rivers that it dances above. Perhaps they imagine it to have hints of purple or red. Why this is so is because they have been influenced by images, found anywhere from books to websites, or even shots on a digital camera. It is pretty easy to fall into the trap of thinking that is what they will see with their own eyes and, all of the way up to the moment that they see the first sliver of light, expectations will be high.

Sadly, these individuals are often disappointed. The aurora borealis isn't as bright and colourful as it appears in the images they have pored over and neither do they seem to dominate the sky in curtains and twisty light trails.

The truth is that the real thing is actually much paler and fainter than what we're made to believe in images. You'll see the dancing of the northern lights, but the strong, bold colours you see in pictures are actually achieved by a photographer, more specifically the camera they are using. It's true that the colours are real, but the moment a camera's shutter opens light gathers onto a sensor that's much more sensitive than your eyes and creates the exaggerated green, red or purple aurorae that you see in books and on websites.

That's not to say that you won't see any colours, however. While it's more common to see a pale, colourless aurora in the northern sky, some have reported seeing slight tinges of green or hints of pink. In general though, your eyes are blind to the colours of the northern lights. It is only a camera and the magic of timed exposures that's able to pick out anything other than white.

Despite many of us being frustratingly colourblind to it, the aurora borealis is still a magical experience to behold. Its unpredictable dance in the night sky, its changes in intensity and even the sheer excitement of waiting for it to arrive all add to the effect of a jaw-dropping wonder to witness.

Remember that it's often a waiting game when it comes to aurora hunting. It's said that the best time to find the aurora is between the hours of 10:00pm and 3:00am during times of peak solar activity. However there will be times where you'll be waiting out in the cold for hours, not seeing the aurora at all on your trip, along with varying degrees of activity. Despite this you should wrap up warm, check aurora forecasts, stay awake and be ready – it's very easy for a show to be over before it's really had a chance to begin.

What do I need?

- ☑ Hat, scarf and gloves
- ☑ Thermals
- ☑ Waterproof jacket
- ☑ Winter boots
- ☑ Flask with a hot drink
- ☑ Red torch
- ☑ Geographical map
- ☑ Mobile phone

Using the Moon to your advantage

In general, any form of light pollution can wash out night-sky astrophotography but, in some cases, you can use it to your advantage. If you're in a snowy landscape then our natural satellite can play up terrestrial views to compliment aurora borealis hanging overhead.

Lights, camera, action: imaging the northern lights

Get those vivid greens, purples and reds in your shots

It's easy to be unprepared when it comes to imaging the northern lights, and though it's true that the advent of the digital camera has reduced the trial and error that comes with slide films, capturing the northern lights still takes practice, planning and patience.

Your imaging checklist

- ☑ **Decide if you want to shoot in RAW or JPEG – beginners may prefer JPEG for now**
- ☑ Set your camera's LCD brightness to low
- ☑ **Remove the filter from your lens – this will ensure that you don't have 'rings' in your images**
- ☑ Test camera exposure
- ☑ **Ensure you have a sturdy tripod and good ballhead**
- ☑ Keep a spare set of batteries and flash cards in your pocket. Cold conditions can drain batteries very quickly and shooting in RAW format can take up a lot of space on your device
- ☑ **Get a lens hood to protect from frost and condensation**

It's a given that to get the best displays of the northern lights possible you should find a location within the auroral belt as well as avoiding any light pollution from the Moon or artificial sources, such as street lights. A great proportion of your shooting will be between northwest and southeast directions in the sky, so with this in mind, ensure that you have positioned your camera and tripod with glaring light sources to your south.

If you have checked aurora forecast reports and have headed out to be confronted with a very weak aurora, don't be too put off: there's still an opportunity for you to image the northern lights. Weak activity is still acceptable for photography, particularly if you're in a relatively northern position.

When it comes to kit, you should ensure that it is of very good build and comfortable to use. A tripod that's tall enough as well as a good ballhead - we recommend these over pan/tilt heads - will make it easier for you to image the northern lights. Anything less will only make an already difficult venture even more frustrating.

Nowadays many imagers like to use DSLR cameras and ensure that the settings of their camera allow for long exposures and high ISO noise reduction. Being prepared means that you should also have your gear ready to go at a moment's notice. If you're unsure of how your camera's settings work it's a good idea to test it beforehand. You should ensure that you have removed your camera's lens filter and pre-focused your device on a distant point like a mountain just before it gets dark.

As a general rule of thumb, setting a camera with an aperture of f/2 to f/2.8 or wider to an exposure time of three to 30 seconds with a sensitivity of ISO 800 to 1600 should get very good shots of the northern lights.

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“It will unite robotic space survivability with human ingenuity to create a whole new age of space exploration”

© JAXA; Clouds Architecture Office; Adrian Mann; Haduboki / Getty

AVATARS IN SPACE

A new initiative has been launched to develop real-life robots that allow humans to venture into space… without actually leaving Earth

Written by Lee Cavendish

Space can be a dangerous place for a human. There are a number of factors in the way of human exploration of space. Even before you leave Earth's gravity the initial ascent on a tin rocket packed with flammable fuel could end badly. Once in space the protective layer of the atmosphere is gone and you are subject to harsh radiation. With further advances in technology year after year there is a strong argument for the development of an intelligent robotic presence in space. Not artificial intelligence, but humans controlling a robotic body. This is why the Japan Aerospace Exploration Agency (JAXA) and All Nippon Airways (ANA) have launched the AVATAR X program. This initiative to create ground-controlled robots in space will revolutionise space exploration and discovery.

Space probes have been scientists' main source of exploration for decades now; with the rapid improvement of technologies there is a swarm of orbiters, landers and rovers scattered throughout the Solar System. Just above Earth, gliding through low-Earth orbit, is the International Space Station (ISS), capable of accommodating six astronauts at a time. In the outer Solar System NASA's Juno spacecraft is gathering valuable data about the gas giant Jupiter, and even farther beyond that the New Horizons spacecraft is making the first approach to a Kuiper Belt object nicknamed Ultima Thule. By looking at these examples, it is safe to say that man-made spacecraft are better suited to exploring the cosmos than humans are.

But how does it get better? With evolving technologies comes the evolution of human innovation and creative thinking, and this is exactly what the ANA-JAXA AVATAR X program will bring to the table. Although the programme is in its early stages of development its ambitions are clear - to put a real-life, robotic avatar into space for humans to control back on Earth. It will unite robotic space survivability with human ingenuity to create a whole new age of space exploration.

This idea came about as a result of ANA's AVATAR Vision and JAXA's new research and development programme, JAXA Space Innovation through Partnership and Co-creation, or J-SPARC. It is not just these two organisations that are involved; there are a whole host of names that include Meltin, a company specialising in developing cyborg technology, and XPRIZE, the same company that cofounded the Google Lunar XPRIZE. The ANA Avatar XPRIZE is a $10 million (£7.9 million) prize for the clever mind, or minds, that can develop real-life avatars over a four-year global competition.

"Our ability to physically experience another geographic location, or to provide on-the-ground assistance where needed is limited by cost and the simple availability of time," says XPRIZE founder and executive chairman Dr Peter H. Diamandis. "The ANA Avatar XPRIZE can enable creation of an audacious alternative that could bypass these limitations, allowing us to more rapidly and efficiently distribute skill and hands-on expertise to distant geographic locations where they are needed, bridging the gap between distance, time and cultures."

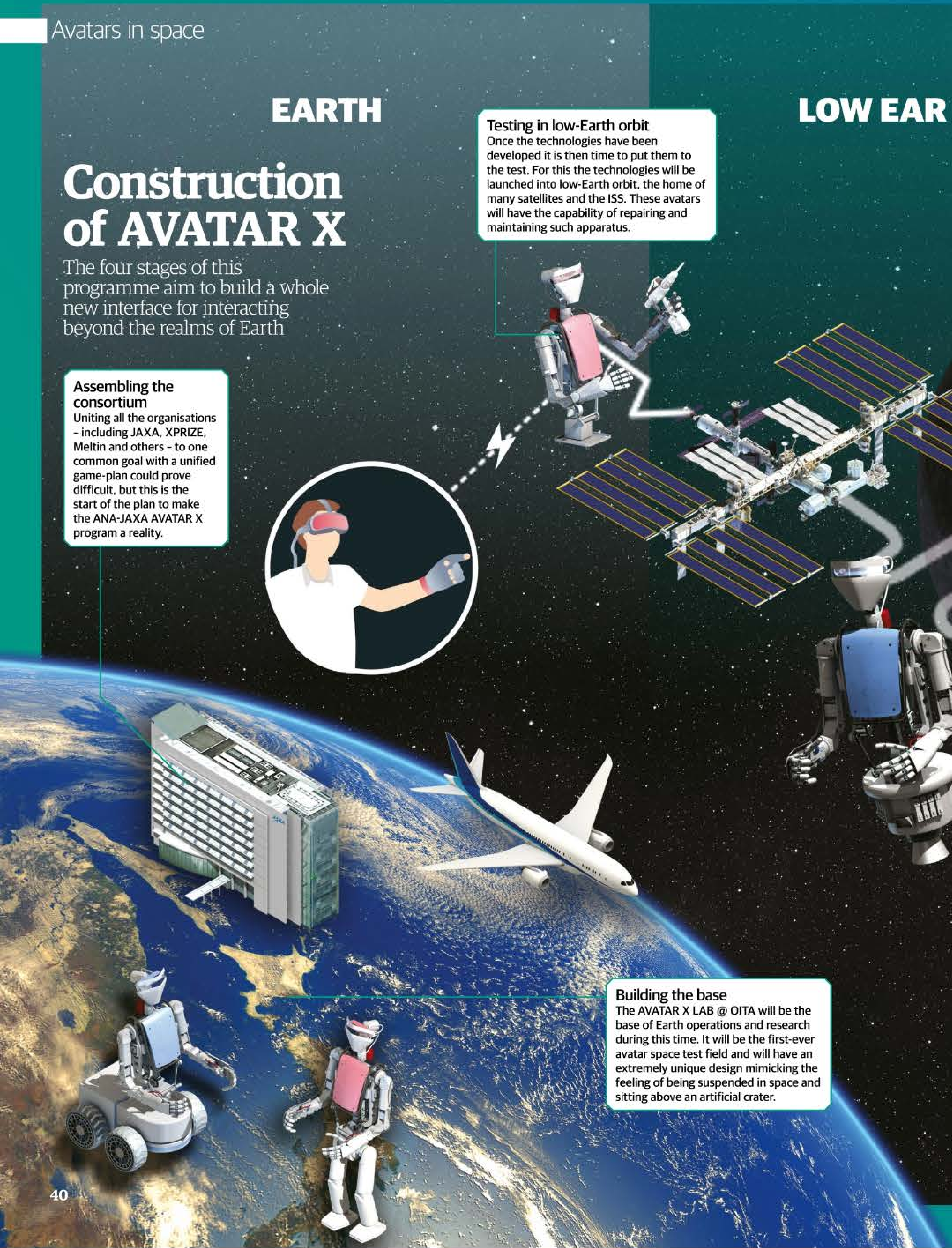
To make this science-fiction idea a reality there are many phases to the plan, which begins with developing a base on Earth, as well as the actual avatars. Then comes the testing beyond the confines of Earth. When up and running the AVATAR X team hope that the avatars will aid construction in space, including on the lunar surface and beyond; the operation and maintenance of space stations from Earth, such as the ISS and the future Deep Space Gateway and even space-based entertainment and travel for the public, benefiting from the commercialisation of space.

The first phase in this plan is assembling the AVATAR X consortium, which has already started

The research and development site will develop the ideas outlined by the AVATAR X consortium

Construction of AVATAR X

The four stages of this programme aim to build a whole new interface for interacting beyond the realms of Earth



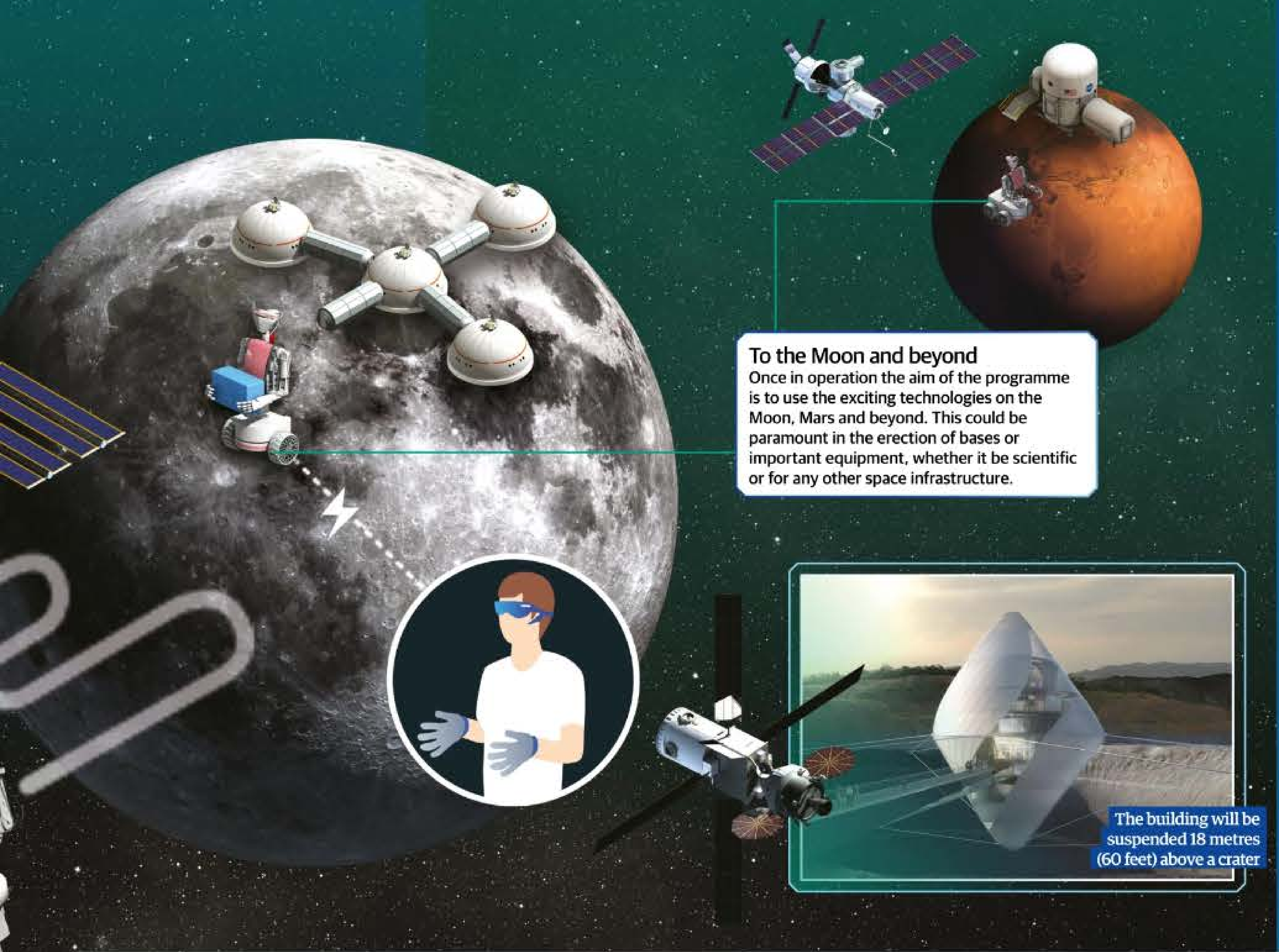
Assembling the consortium
Uniting all the organisations – including JAXA, XPRIZE, Meltin and others – to one common goal with a unified game-plan could prove difficult, but this is the start of the plan to make the ANA-JAXA AVATAR X program a reality.

Testing in low-Earth orbit
Once the technologies have been developed it is then time to put them to the test. For this the technologies will be launched into low-Earth orbit, the home of many satellites and the ISS. These avatars will have the capability of repairing and maintaining such apparatus.

Building the base
The AVATAR X LAB @ OITA will be the base of Earth operations and research during this time. It will be the first-ever avatar space test field and will have an extremely unique design mimicking the feeling of being suspended in space and sitting above an artificial crater.

TH ORBIT

MOON, MARS AND BEYOND



To the Moon and beyond
Once in operation the aim of the programme is to use the exciting technologies on the Moon, Mars and beyond. This could be paramount in the erection of bases or important equipment, whether it be scientific or for any other space infrastructure.

The building will be suspended 18 metres (60 feet) above a crater

The site for the AVATAR X LAB will be at the southern prefecture of Oita, Kyushu, Japan

© JAXA; Clouds Architecture Office; Adrian Mann

with a long list of names already signed up to the cause. With AVATAR X welcoming the help of different companies and organisations from all sectors that are interested in taking up the challenge of this pioneering space adventure, the consortium can be officially established. Once established the official forum can begin to discuss the plan of action and road map for the future of the AVATAR X program. This phase may take a few years, as collaboration is key, and gathering the organisations and collectively deciding on an agenda will take a fair amount of time - you can't build a great building on a weak foundation.

Once the consortium is decided on, the next step is to build the AVATAR X LAB @ OITA. This building will be the Earth-based haven of the AVATAR X operation. The site will be located in Japan's southern prefecture of Oita, Kyushu, and will be the world's first dedicated avatar space-test field. The building will be designed by the award-winning architecture firm known as CLOUDS Architecture Office (CLOUDS AO). Preliminary designs of the lab are exquisite, and if constructed it will be a feat of architectural design with a unique idea to have a building held in suspension above a 'crater'. The reasoning behind this design is that it will embody the idea of 'being in the air' 18 metres (60 feet) above a moon-like crater, with the building accessible by a bridge.

This building will be home to the key telecommunication and research facilities that will enable testing for avatars in space scenarios. There will also be conference rooms, exhibition rooms, restaurants and other such amenities that will be available to the researchers and visitors that come and go. This level of creativity alone mirrors the task in hand for the AVATAR X program.

The third phase will occur in the early 2020s, and consists of taking the technologies created and developed at the AVATAR X LAB @ OITA and putting them into low-Earth orbit, which can be anywhere between 160 to 2,000 kilometres (99 to 1,243 miles) above the Earth's surface. This launch to low-Earth orbit will be used primarily for testing purposes, and tasks that can be performed in this region of space could potentially involve supporting astronauts on a space station, conducting scientific experiments and internal and external maintenance jobs. This could also be valuable in constructing, refuelling, servicing and repairing satellites and space probes in Earth orbit. Considering the ever-increasing population of satellites around Earth, to have robots in space 'doing the dirty work' would increase the lifetimes of many satellites.

> "ANA is driven by a bold and inspiring vision of the future of flight, and this boldness doesn't stop on our planet"
>
> **Shinya Katanozaka**

MELTIN have already begun designs of what the avatars will look like, and have given it the name MELTANT-α. This long-distance remote-controlled robot will protect astronauts from the dangers of space while performing all the tasks needed. MELTIN have identified that in order to achieve the tasks that humans need to do, the robots have to have abilities close to that of a human. This is why they have designed MELTANT-α to have human-sized hands with the same speed, flexibility, power and haptics. Their fingers will allow for the same high-precision work that humans can perform.

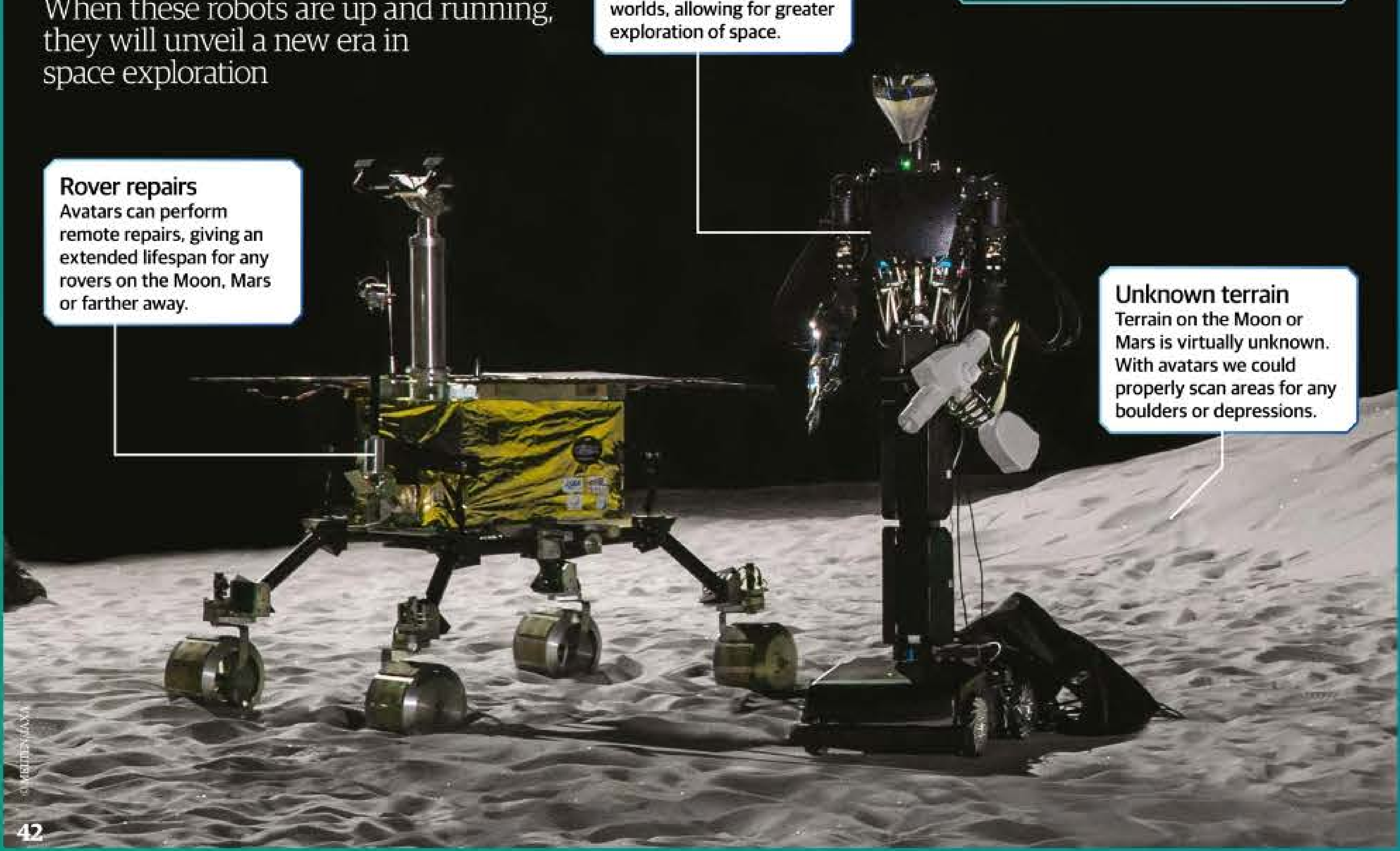
At this point, which is set for a time unknown, the fourth and final phase can take shape. The AVATAR X can finally be unleashed into the wilds of space and can begin with the building of bases, maintenance of rovers and other pieces of equipment, as well as providing valuable scientific data from afar. The most likely scenario is that the avatars will first be deployed on the Moon, hopefully venturing on to our neighbouring planet, Mars. This will not only be safer as opposed to using humans, it will be more cost effective and make several areas of space more accessible, all the while being controlled from the comfort of Earth.

"ANA is driven by a bold and inspiring vision of the future of flight, and this boldness doesn't stop on our planet," concludes Shinya Katanozaka, president and CEO of ANA. "Through innovative partnerships like AVATAR X, we are excited about the possibilities of what we can accomplish and where we can go when the private and public sectors join forces."

MELTANT-α will be remotely controlled by humans

Avatars touch down

When these robots are up and running, they will unveil a new era in space exploration



Human control
Human intelligence with robotic accessibility presents the best of both worlds, allowing for greater exploration of space.

Rover repairs
Avatars can perform remote repairs, giving an extended lifespan for any rovers on the Moon, Mars or farther away.

Unknown terrain
Terrain on the Moon or Mars is virtually unknown. With avatars we could properly scan areas for any boulders or depressions.

© MELTIN/ANA

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ASK Space

Our experts answer your questions

SPACE EXPLORATION

How much has space exploration progressed since the Apollo missions?

Well, it's hard to tell. I think right now they're focusing on getting commercial spacecraft to fly people to the space station, but in the background there is a long-range programme with [the Space Launch System rocket] and [the Orion spacecraft] that will eventually allow us to go beyond Earth orbit, like going to Mars. But right now it's not an active part of launching because we're between programmes I guess, and so it's going to be a few years before they get the long-range exploration going with the new spacecraft. I would expect it's going to be another 10 or 15 years before we get back into the exploration business.

Eventually we're going to have to do something a little different than just that gumdrop-shaped capsule because there are some problems with re-entry and that sort of thing – you have to be very careful. But the day will come when we're going to have spacecraft that'll go way, way beyond even the Solar System, so that'll take a different shape. But in the meantime we've got Orion, which is basically an enlarged Apollo spacecraft, and it can do the next step.

Alfred Worden was the Command Module pilot for NASA's Apollo 15 lunar mission

"It's going to be a few years before they get the long-range exploration going"

NASA is currently looking into a return to the Moon, as well as a proposed lunar gateway

ASTROPHYSICS

Is there a chance that Einstein's theory of general relativity isn't enough to explain the universe?

Einstein's theory for gravity is appealing and has been so popular for nearly a hundred years because of its conceptual - if not mathematical - simplicity. It is possible that it might be too simple, however, and some sophistication might need to be added. By doing so we won't need to radically change our theories for the universe's history, but it will change our predictions for our universe's future: an accelerated expansion has the unfortunate consequence of an eventual 'Cosmic Rip', whereas we might be in for a less cataclysmic future if gravity acts differently to our current assumptions.

Dr Kathy Romer is an astrophysicist at the University of Sussex

A 'Big Rip' is one way the universe could end

Did you know?

Einstein's general theory of relatively predicated gravitational waves over 100 years ago, and today we have made several detections, proving him right!

ASTROPHYSICS

What is the best evidence we have for black holes?

For 20 years astronomers have studied the detailed motions of 100 individual stars at the centre of our galaxy around a mysteriously empty region known as Sagittarius A*. These orbits imply that there is a huge source of mass of over 4 million Suns cramped into a region not much bigger than our Solar System… [Here we] see no extra light, certainly nothing close to a million Suns' worth. They represent a pivotal turning point in our understanding of nature: they are regions of space where time itself comes to an end. They form as an inescapable consequence of Einstein's general theory of relativity, and their discovery and confirmation represent a huge success for physics. [The] most important aspect of black holes is that they go beyond even relativity - they predict a region of infinite density and pressure, the singularity, where the laws of physics will cease to exist. Today physicists interpret this as a sign that the theory of relativity is incomplete.

Dr Asa Bluck is an astronomer at the University of Victoria, Canada

Black holes are difficult to detect because of their very nature

MAVEN has been sending data back from Mars since 2014

PLANETS

What can Mars' atmosphere tell us?

Understanding the history of the atmosphere is a driver to understanding the geological and potential biological history of the planet. We see a lot of evidence that the climate on Mars has changed. For example, we see geological evidence from liquid water early on, yet the water disappeared - we just see cold, dry ice on the planet today. What conditions allowed water to be present as a liquid early on? Most people think that there had to be a thicker greenhouse atmosphere, so the question immediately becomes: 'Where did the water go and where did the carbon dioxide from a greenhouse atmosphere go? We're studying the upper atmosphere with missions like MAVEN as a way to answer those questions because loss of the gas to space is one of the processes that we think was very important. What we want to do is understand how important that process was and to determine whether loss to space out the top of the atmosphere was perhaps even the dominant process in the history of the atmosphere and the changing climate. That's going to tell us a lot about what controls the geological history of Mars and what controls its habitability.

Bruce Jakosky is the principal investigator of the MAVEN mission, currently at Mars

© NASA; Tobias Roetsch

ASK Space

Our experts answer your questions

PLANETS

Could Pluto still be classified as a planet?

Scientists typically classify objects into groups based on natural boundaries. [When looking at] the size and orbits of objects in the Solar System, it's clear the largest eight objects stand apart and deserve the name 'planets'. When Pluto was discovered it was thought larger than Earth and isolated, hence a planet.

Now that we understand Pluto is small and simply part of the Kuiper belt [it has been demoted to a dwarf planet]. Many Pluto-sized and smaller objects exist there, and so there is no natural dividing line between. If a line is artificially drawn to make Pluto a planet, there will always be two objects of almost the same size and appearance, but one will be a planet and the other won't.

Hal Levison is a planetary scientist at the Space Studies Department of the Southwest Research Institute in Boulder

EXOPLANETS

Could life elsewhere have formed in a similar way to that on Earth?

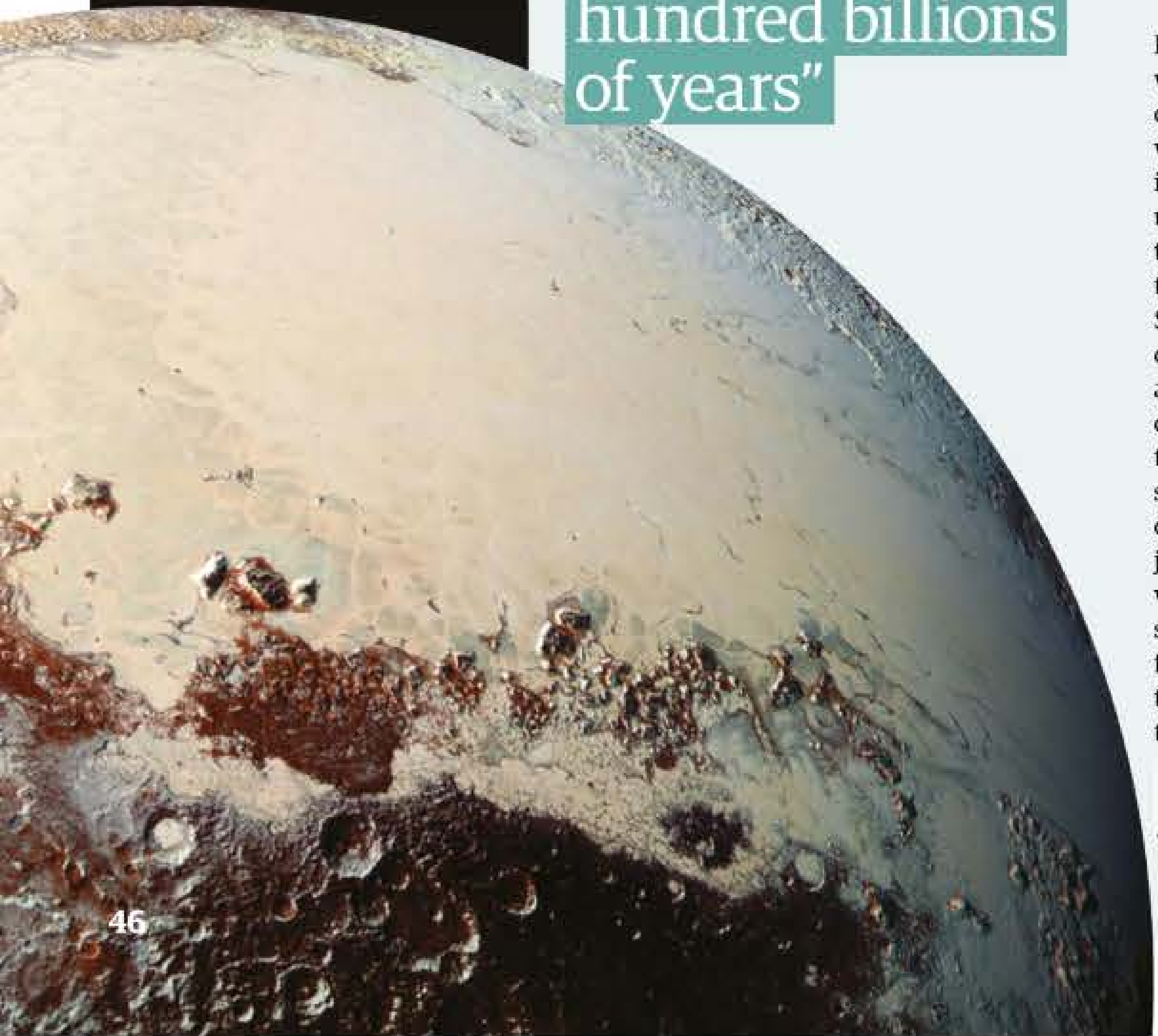
The early history of the Solar System contained collisions and explosions. We know that the age of the Earth is around 4.5 billion years old. It's by coincidence that it is one-third the age of the universe. The Earth-Moon system was most probably made by a collision and by an object the size of Mars.

For hundreds of millions of years many meteorites, asteroids and comets bombarded the Earth. Life would not have formed in these early times because our planet was too hot and it would have been very dry, so there would have been no possibility of this.

At around the same time that the rocks stopped falling, the Earth started to cool down. The first signs of an ocean started to appear. We even have fossils that show evidence of life within a few hundred billions of years - that's about the same time that life could have possibly occurred here. How life came to evolve on our planet is strong evidence that life can evolve elsewhere in the universe. Intelligent life - that's us - has only really turned up quite recently. We ourselves are made out of star material. Stars that explode send chemical material into space. Some of it is recycled and some of it travels outside of our galaxy to make the next generation of stars that could have planets - worlds that could be like Earth. So that's the idea: stars explode and make future generations of stars and planets.

John Mather is an astrophysicist at the NASA Goddard Space Flight Center

> "We have fossils that show evidence of life within a few hundred billions of years"



SPACE EXPLORATION

What's it like going on a spacewalk?

It's perfectly appropriate to call it spacewalking - we all do - but when we are in Earth orbit, outside on a 'spacewalk', we're actually crawling hand-over-hand using handrails on the outside of whatever we happen to be working on. We're not truly walking, but it is an incredible human experience. I think it is the greatest job in the universe to be outside in your own personal 'spaceship' with just a thin visor between you and the enormity of the universe. You have to have on your back - or surrounding your body - everything that a Space Shuttle has in terms of systems to sustain you there. You need oxygen delivery, carbon dioxide removal and temperature control and protection from the vacuum of space. You need radios, TV cameras, battery power, cooling and lighting; you need a computer to see what is going on with your spacesuit and tools on the front of your suit. There's even a little jet backpack on your back that will enable you to fly yourself to safety if you were to float free from the space station. So I really think it is a dream to get a chance to go outside on a spacewalk.

Scott Parazynski is a former astronaut and physician

ASTROPHYSICS

Are gravitational waves just made by black holes?

They're produced by pretty much anything: you, me, cars, planes. But we're tiny, and space is very 'stiff' - it really doesn't like to deform - and so while we do produce gravitational waves they're minuscule in terms of amplitude. To get a signal that's strong enough to measure on Earth it really has to be a very big, violent event in the universe. Waves are created by an acceleration of mass, so if you think of two objects orbiting each other you can have an angular acceleration - if you view two stars orbiting from a long way away then at some times you see the two stars separated, with one gravity field, and at other times they're roughly in line. Ground-based gravitational-wave experiments like LIGO in Louisiana and VIRGO near Pisa in Italy are looking for events involving stellar-mass objects - things like neutron stars, supernovae and stellar black holes - up to about ten-times the mass of the Sun. But up in space we're hoping to look for the really big guys - like galaxies smashing into each other and stuff like that.

Paul McNamara is an astrophysicist based at the European Space Agency

ASTRONOMY

Why do we use radio to observe the universe?

Well there's particular science that can only be done in radio wavelengths, and you just need to look back at the last 30 or 40 years or so of astronomy – a lot of the big discoveries have been made at radio wavelengths. So particularly the pulsars, which were discovered in the UK, could not have been done in any other wavebands. I'd say that this is a very big example of needing to study the universe in radio wavebands.

Things like looking at complex molecules, which are very interesting for people looking for life in the universe, is another example and one which is going very well in the radio wavelengths. And looking back in time is also very good in long radio wavelengths, since they can see through all of the obscuring matter in space in order to go way back to the beginning of the universe, which can be very hard to do at optical wavelengths and other wavelengths. It's the way that a lot of astronomy has been done.

Tyler Bourke is a project scientist for the Square Kilometre Array

© NASA; ESO; Tobias Roersch; Mike Peel; Arizona State University

INSIGHT HAS LANDED AND IS READY TO PROBE MARS

NASA's highly anticipated InSight lander has finally touched ground on the dry Red Planet

Scientists rejoiced as NASA's Seismic Investigations, Geodesy and Heat Transport (InSight) lander successfully landed on 26 November at Elysium Planitia, bringing about a whole new outlook on investigations of the Red Planet.

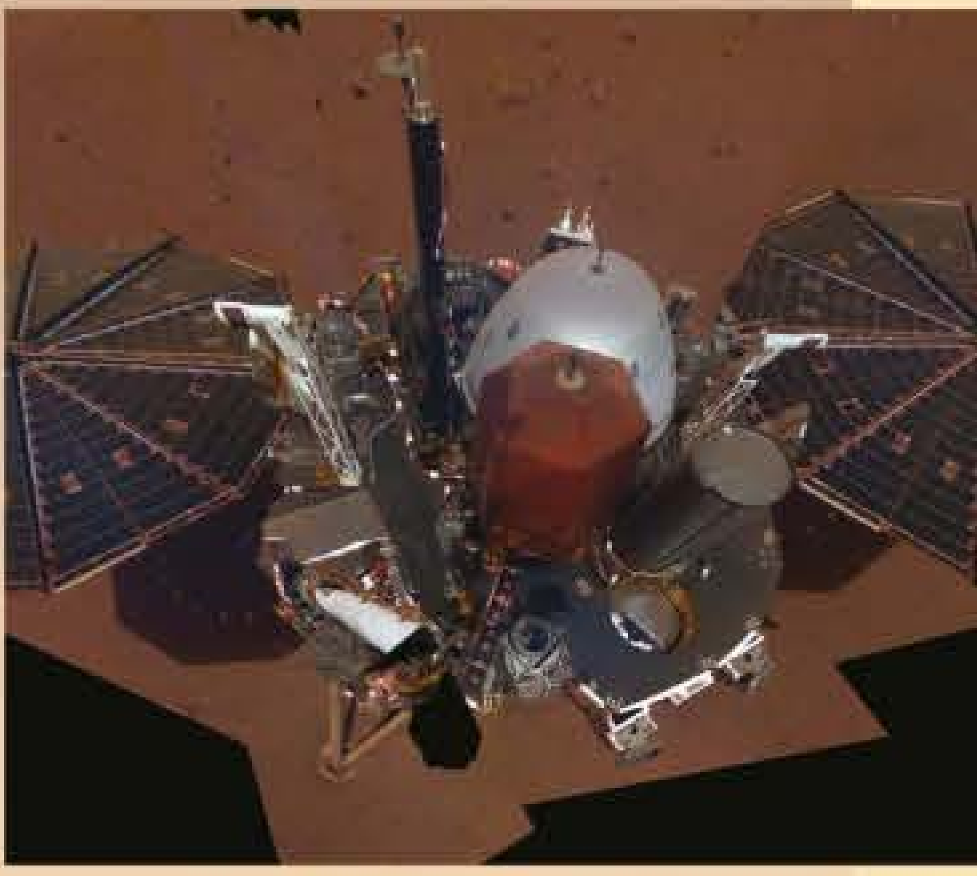
After a seven-month, 485-million-kilometre (300-million-mile) journey InSight had to take on the hardest challenge for a Martian lander: reducing its speed through a virtually nonexistent atmosphere for a safe landing. "We hit the Martian atmosphere at 12,300 miles per hour [19,800 kilometres per hour], and the whole sequence to touching down on the surface took only six-and-a-half minutes," says InSight project manager Tom Hoffman at NASA's Jet Propulsion Laboratory in Pasadena, California, United States. "During that short span of time InSight had to autonomously perform dozens of operations and do them flawlessly – and by all indications that is exactly what our spacecraft did."

When landing was complete surface operations commenced. There were still boxes to tick, the first of which was deploying the two decagonal solar arrays which will harness the weaker rays of the Sun to power the spacecraft. This was accomplished without a glitch and confirmation was relayed back to Earth via NASA's Odyssey spacecraft. These events were performed without any scientists' knowledge as communications between mission control and InSight are delayed by five-and-a-half hours due to the enormous distance.

"Landing was thrilling, but I'm looking forward to the drilling," says InSight principal investigator Bruce Banerdt of JPL. "When the first images come down our engineering and science teams will hit the ground running beginning to plan where to deploy our science instruments. Within two or three months the arm will deploy the mission's main science instruments, the Seismic Experiment for Interior Structure (SEIS) and Heat Flow and Physical Properties Package (HP3) instruments."

As of 6 December 2018 InSight has also successfully deployed its two-metre (six-foot) robotic arm and showed it's ready for action. The Instrument Deployment Camera located on the elbow of the robotic arm will take many photos of the terrain surrounding the lander and create a full mosaic. These images will help the mission team in deciding where to place SEIS and HP3. Every task that has been – and will be – undertaken will make or break the mission, and it's the fine margins that will lead to the most ground-shaking discoveries of Mars and its elusive interior. By probing deeper than any lander before it, the results from this mission will reveal the evolution of the planet and understand why it appears so geologically inactive.

> "Within two or three months the arm will deploy the mission's main science instruments"

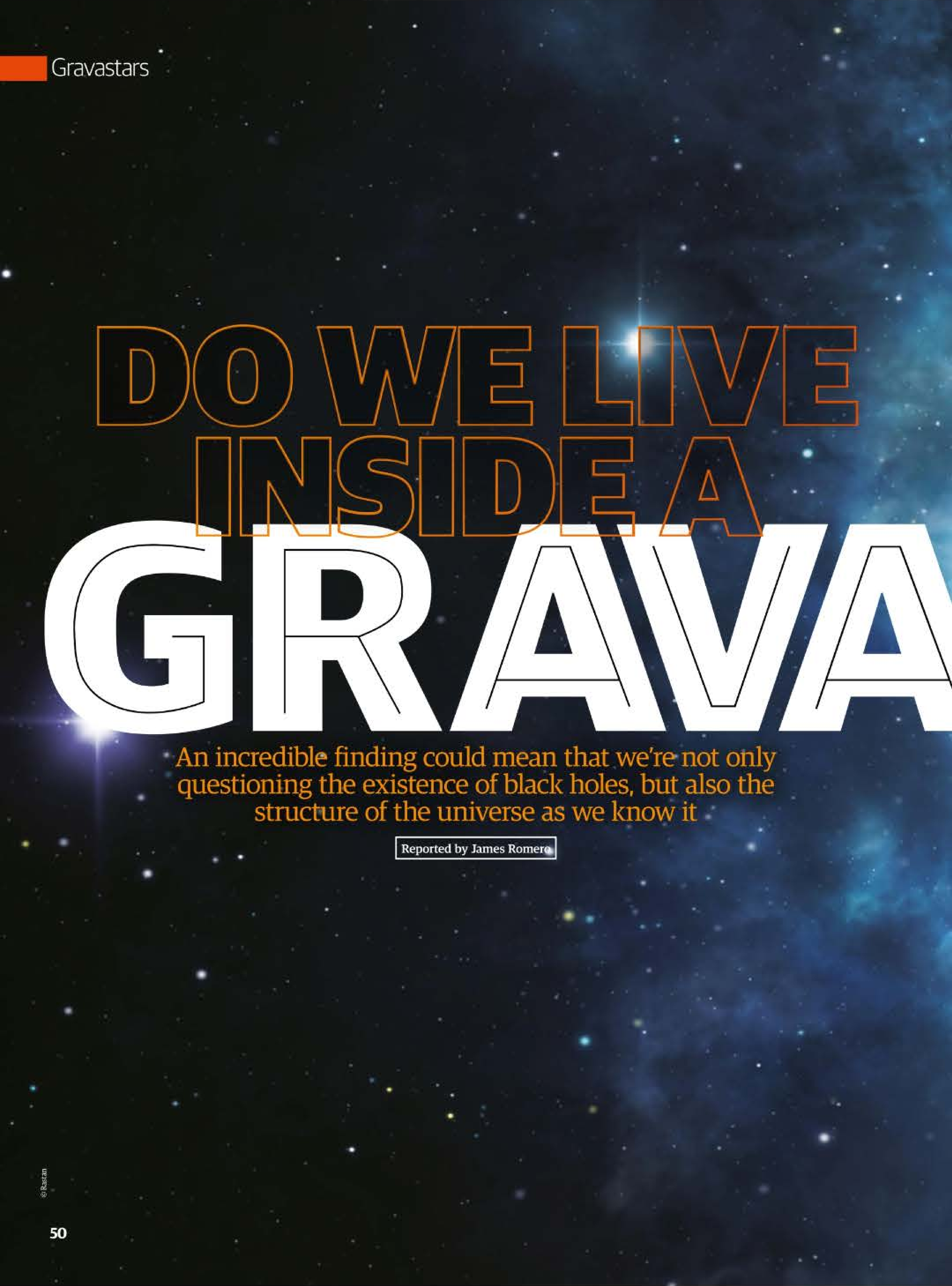


Above: InSight's first selfie is a mosaic image made up of 11 images taken with its Instrument Deployment Camera

Left: One of the first images taken of Mars with InSight's Instrument Context Camera (ICC) – there are many more to come

Above: InSight team members Kris Bruvold, left, and Sandy Krasner, right, appear ecstatic after receiving confirmation of the successful landing

© NASA/JPL-Caltech; Adnan Mann



DO WE LIVE INSIDE A GRAVA

An incredible finding could mean that we're not only questioning the existence of black holes, but also the structure of the universe as we know it

Reported by James Romero

© Rastan

ASTAR?

In 2001 two physicists proposed a solution to 70 years of debate around black holes, the most extreme, mind-bending objects in the universe, by replacing them entirely. Their alternative, named a gravastar, could solve fundamental paradoxes raised by Stephen Hawking. Some even believe our entire universe may exist inside one. Now, after time out of the spotlight, interest in gravastars is returning, fuelled by the real possibility we could soon prove their existence once and for all.

An insatiable appetite and the ability to bend reality, virtually stop time and turn people into spaghetti, or perhaps just transport them to new parts of the universe or a whole new dimension? The possibilities associated with black holes since they were first proposed challenge even the most imaginative mind's ability to comprehend what our best scientific theories tell us should be so.

It's not surprising they have given science-fiction writers and Hollywood the vehicles and inspiration for some of their most elaborate plot lines.

A product of the violent deaths of the largest stars in the cosmos, the resulting runaway collapse of the stellar core under gravity eventually produces a singularity, a single point of infinite density and curvature of space-time. Its unimaginable attractive force means any dust, gas or even light that crosses a specified perimeter of no return, the event horizon, is sucked in, like a great whirlpool of seafarer legend.

But do black holes actually exist? To this day we have to infer them indirectly through orbital irregularities which only make sense with the insertion of large centres of mass where none can be seen. Beyond that everything we know about black holes comes from theory and simulation - the extrapolation of Einstein's general relativity to extreme but logical ends.

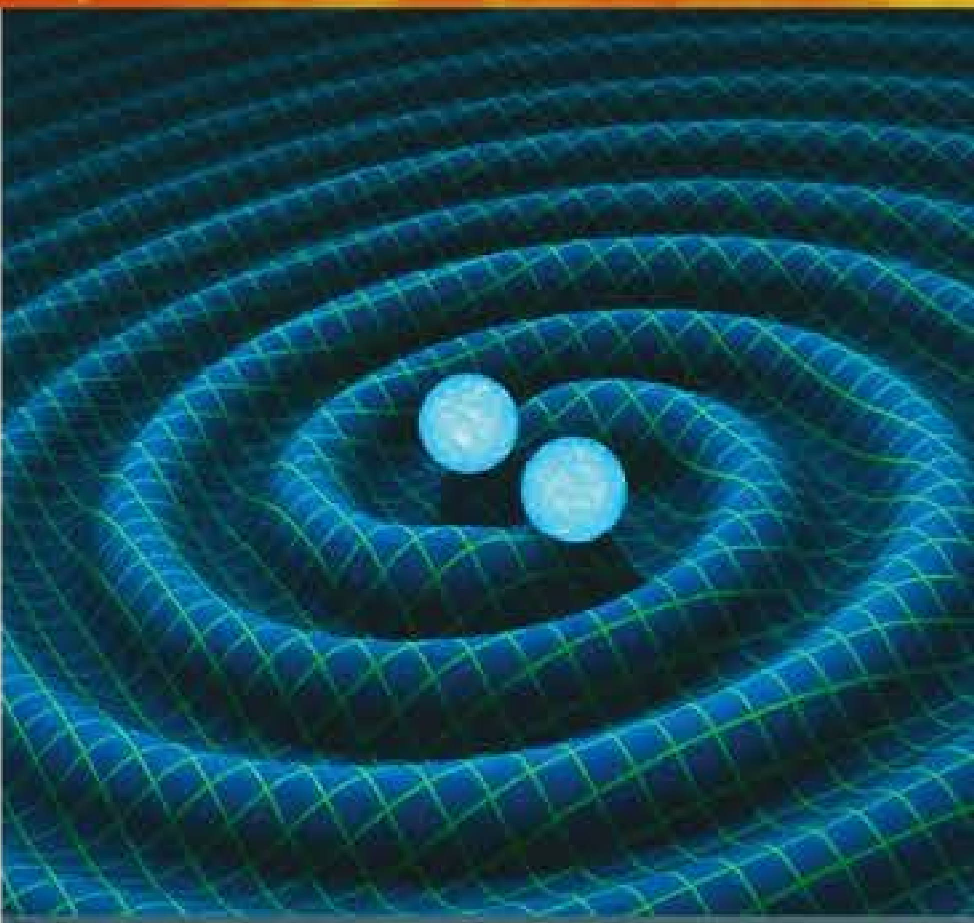
This has opened the door to alternative theories, particularly when the centrepiece of black hole theory, the singularity, stretches not only time and space, but also our fundamental laws of physics. "Singularities are, generally speaking, a breakdown in your physical model," says Emil Mottola, who along with Pawel Mazur proposed the alternative gravastar theory at the start of the millennium.

An example of this theoretical conflict is the information paradox, which concerns not the stuff of the universe itself, but the facts about these objects, the properties of their identity. The laws of the universe suggest information cannot be destroyed, however, a black hole singularity provides no escape mechanism for the information it acquires as it swallows up matter. The radiation continuously coming off black holes, also known as Hawking radiation, shouldn't contain any information. But because energy and mass are equivalent according to Einstein, this radiation means black holes are forever losing mass and will eventually run out. In death they take with them any last chance this captured information could be returned to the wider cosmos.

If a black hole has no singularity then information needn't be trapped and could instead leak out, and yet singularities are an inevitable consequence of our black hole models.

"Once you get inside the horizon there is no way out in the logical sense and the literal physical sense. You are stuck by causality," says Mottola. For many years it was assumed something must intervene, a mysterious influence often vaguely ascribed to 'quantum effects unknown'.

"Black holes have been around for seven to eight decades and people have been trying to resolve these issues for roughly the same time," says Raúl Carballo-Rubio at the Perimeter Institute in Ontario, Canada. "These questions have led people to try and find alternatives."



What is a gravastar?

At the turn of the millennium an equally invisible, but potentially distinguishable alterative to black holes was proposed

Freed from the singularity
Unlike classical black holes gravastars don't contain a singularity, a point of infinite density that breaks our current laws of physics.

A surface you would notice
While you would fall into a black hole, a gravastar's vacuum interior is wrapped inside a shell of quantum matter which you would definitely feel upon impact.

Making waves
Supporters of the theory believe the merger of two gravastars could also have produced the gravitational waves recorded by LIGO.

A black star
The strength of a gravastar's gravitational field means no light coming from them would ever reach us.

A prediction 100 years in the making
In 2015 Emil Mottola showed that much of the groundwork for his gravastar theory had been proposed 100 years earlier by physicist and astronomer Karl Schwarzschild.

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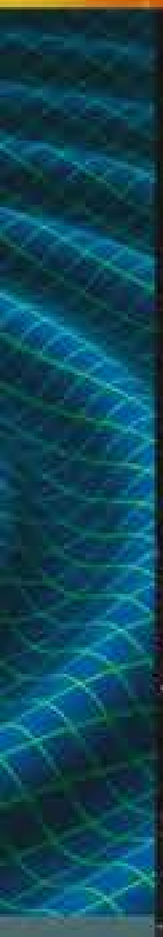
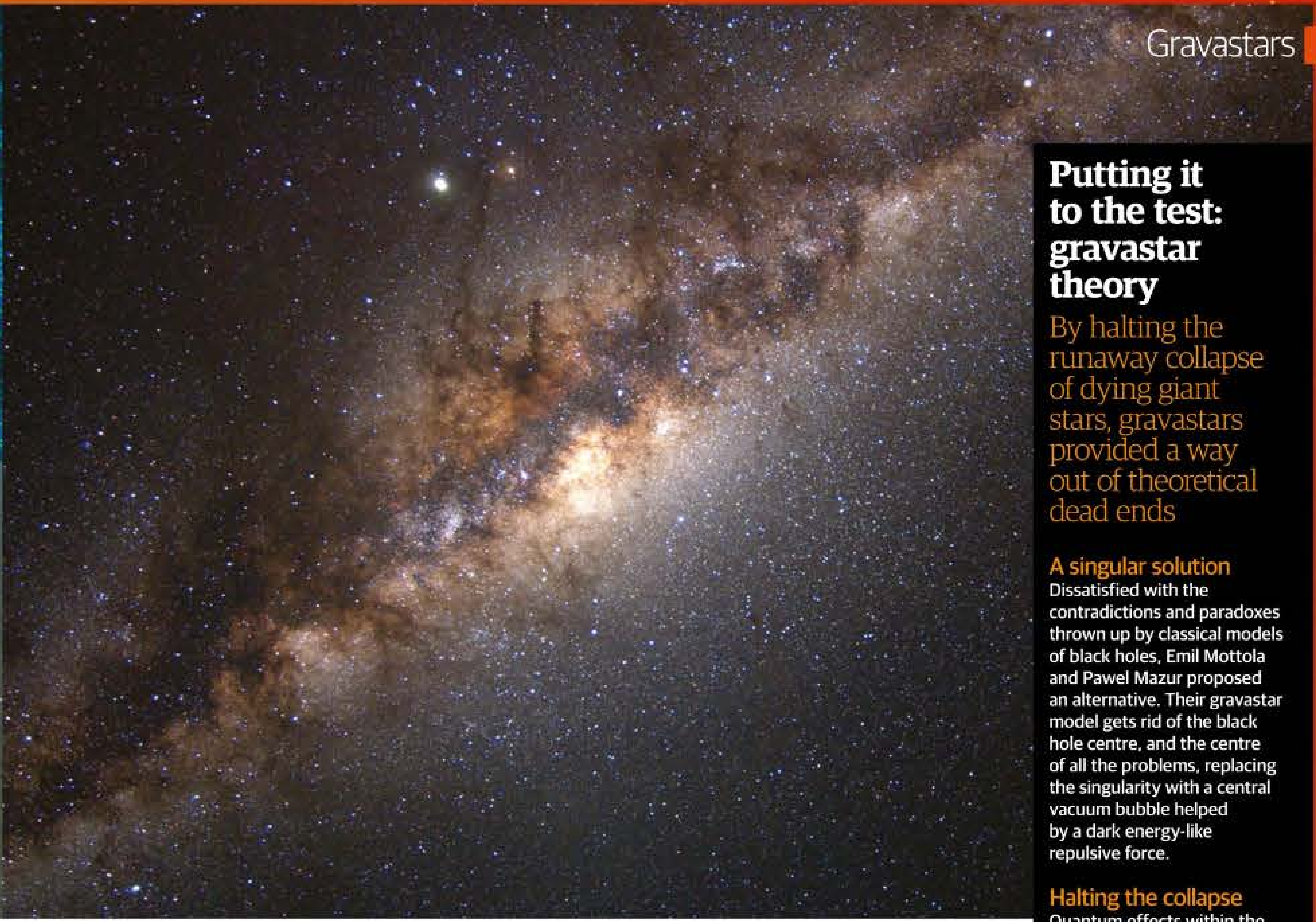




Putting it to the test: gravastar theory

By halting the runaway collapse of dying giant stars, gravastars provided a way out of theoretical dead ends

A singular solution

Dissatisfied with the contradictions and paradoxes thrown up by classical models of black holes, Emil Mottola and Pawel Mazur proposed an alternative. Their gravastar model gets rid of the black hole centre, and the centre of all the problems, replacing the singularity with a central vacuum bubble helped by a dark energy-like repulsive force.

Halting the collapse

Quantum effects within the dying giant star's interior build up during the collapse phase until, eventually, an explosion fundamentally changes the star's interior.

Holding up the roof

Inside the interior a bubble-like vacuum forms, helping against gravitational collapse with dark energy-like repulsive negative pressure.

A thick skin

Any remaining matter not thrown out by the explosion is crushed against the growing vacuum bubble, enclosing it in a layer of strange quantum matter.

> "Black holes have been around for seven to eight decades and people have been trying to resolve these issues" **Raúl Carballo-Rubio**

Mazur and Mottola's contribution took inspiration from recent research into the outward-pushing forces of dark energy that are believed to be accelerating the expansion of the universe. They realised the repulsive properties of dark energy, known as negative pressure, could counter the effects of gravitational collapse that were sending black hole models down the singularity path.

In their gravastar model a classical gravitational collapse during the death of a giant star is halted early enough that neither a singularity, nor a horizon can form. This initial interruption is provided by the build-up of quantum effects which produce an explosive event that dramatically changes the structure of the collapsing star's interior, and a bubble of vacuum is formed, held in place by a dark energy-like negative pressure.

This 'repulsive' core extends out to where the horizon of the black hole would be in the classical model. It replaces the horizon's fictional surface, a purely mathematical point of no return, with a true, solid shell made of ultra-stiff collapsing matter, wrapped around the empty vacuum interior. "You could hit your head, or probably much worse if you struck such a surface," says Mottola.

Their newly imagined objects were named gravitational vacuum condensate stars before the snappier gravastar name was adopted, and were proposed to be almost, but not quite as dense as a black hole.

Mottola laughs when asked about the reaction their ideas received. "It backed directly into the common wisdom about what the interior of a black hole is, and some people are just not willing to entertain this possibility."

Not content with merely rubbing up against black hole modellers, the paper also included what Mottola calls, almost dismissively, "some intriguing speculation" that if correct would "override our entire understanding of a good part of cosmology, inflation and the Big Bang."

This even more contentious idea comes from the following logic: in the interior of gravastars we are invoking the same repulsive negative pressure associated with dark energy. Dark energy is believed to exist throughout the universe at large and account for its seemingly magical quickening expansion. Therefore, could it not be possible that our entire universe might reside within such a gravastar interior?

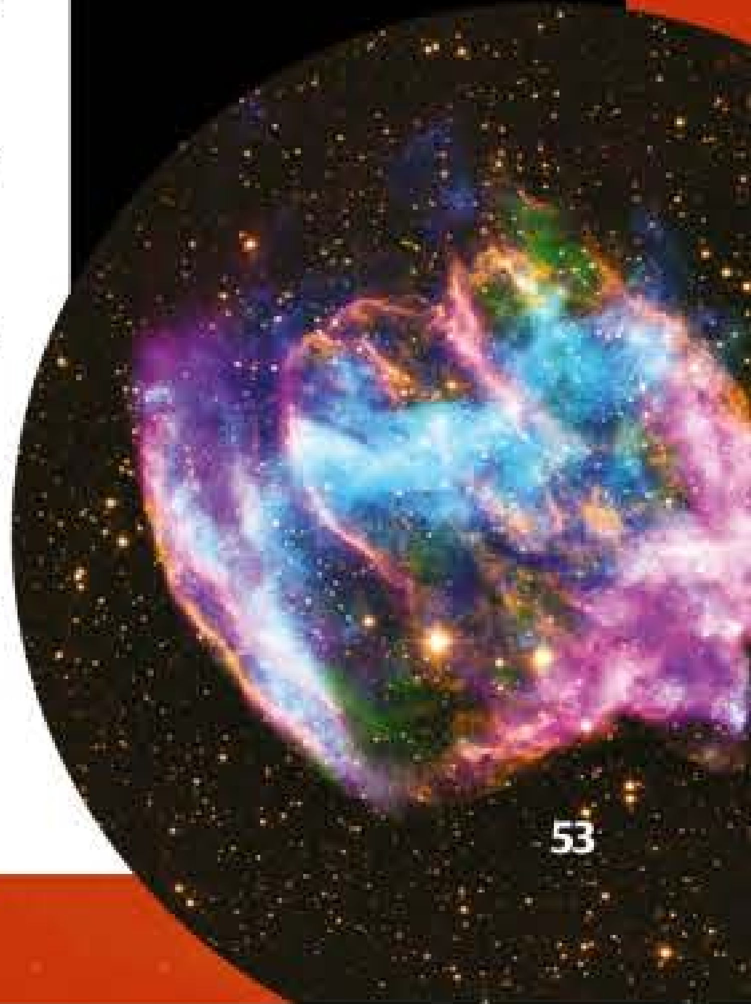
The suggestion was not without precedent. In the 1960s many, including eminent Russian nuclear physicist and Nobel Peace Prize winner Andrei Sakharov, noted that general relativity produces

Clockwise from top left: An artist's impression of gravitational waves

Above: A supermassive black hole, Sagittarius A*, is believed to reside at the centre of our galaxy

Bottom right: Data from NASA's Chandra X-ray Observatory suggests this supernova remnant may contain the most recent black hole formed in the Milky Way

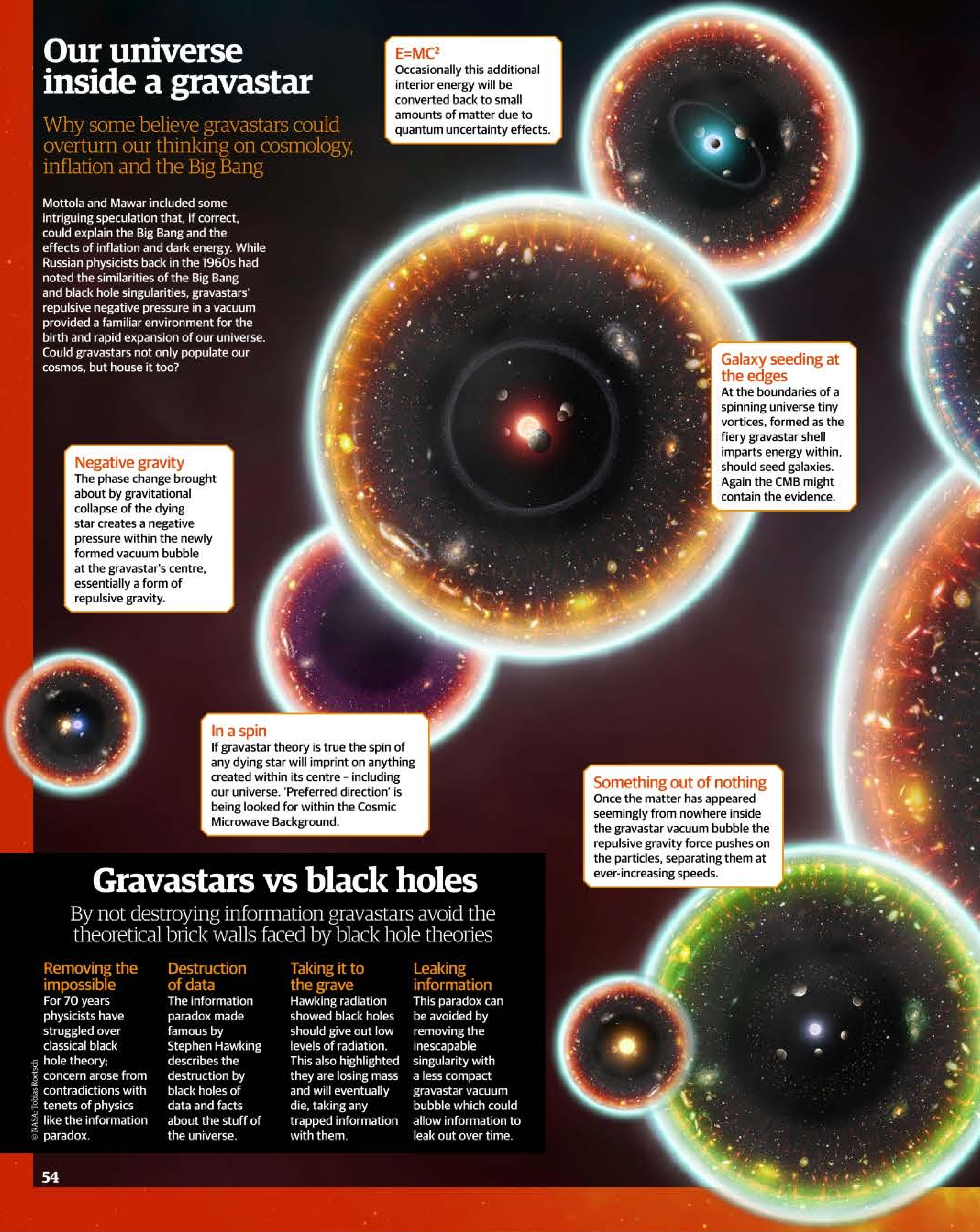
Far left: LIGO, where the first direct gravitational-wave signal was detected



Our universe inside a gravastar

Why some believe gravastars could overturn our thinking on cosmology, inflation and the Big Bang

Mottola and Mawar included some intriguing speculation that, if correct, could explain the Big Bang and the effects of inflation and dark energy. While Russian physicists back in the 1960s had noted the similarities of the Big Bang and black hole singularities, gravastars' repulsive negative pressure in a vacuum provided a familiar environment for the birth and rapid expansion of our universe. Could gravastars not only populate our cosmos, but house it too?



E=MC²
Occasionally this additional interior energy will be converted back to small amounts of matter due to quantum uncertainty effects.

Galaxy seeding at the edges
At the boundaries of a spinning universe tiny vortices, formed as the fiery gravastar shell imparts energy within, should seed galaxies. Again the CMB might contain the evidence.

Negative gravity
The phase change brought about by gravitational collapse of the dying star creates a negative pressure within the newly formed vacuum bubble at the gravastar's centre, essentially a form of repulsive gravity.

In a spin
If gravastar theory is true the spin of any dying star will imprint on anything created within its centre – including our universe. 'Preferred direction' is being looked for within the Cosmic Microwave Background.

Something out of nothing
Once the matter has appeared seemingly from nowhere inside the gravastar vacuum bubble the repulsive gravity force pushes on the particles, separating them at ever-increasing speeds.

Gravastars vs black holes

By not destroying information gravastars avoid the theoretical brick walls faced by black hole theories

Removing the impossible

For 70 years physicists have struggled over classical black hole theory; concern arose from contradictions with tenets of physics like the information paradox.

Destruction of data

The information paradox made famous by Stephen Hawking describes the destruction by black holes of data and facts about the stuff of the universe.

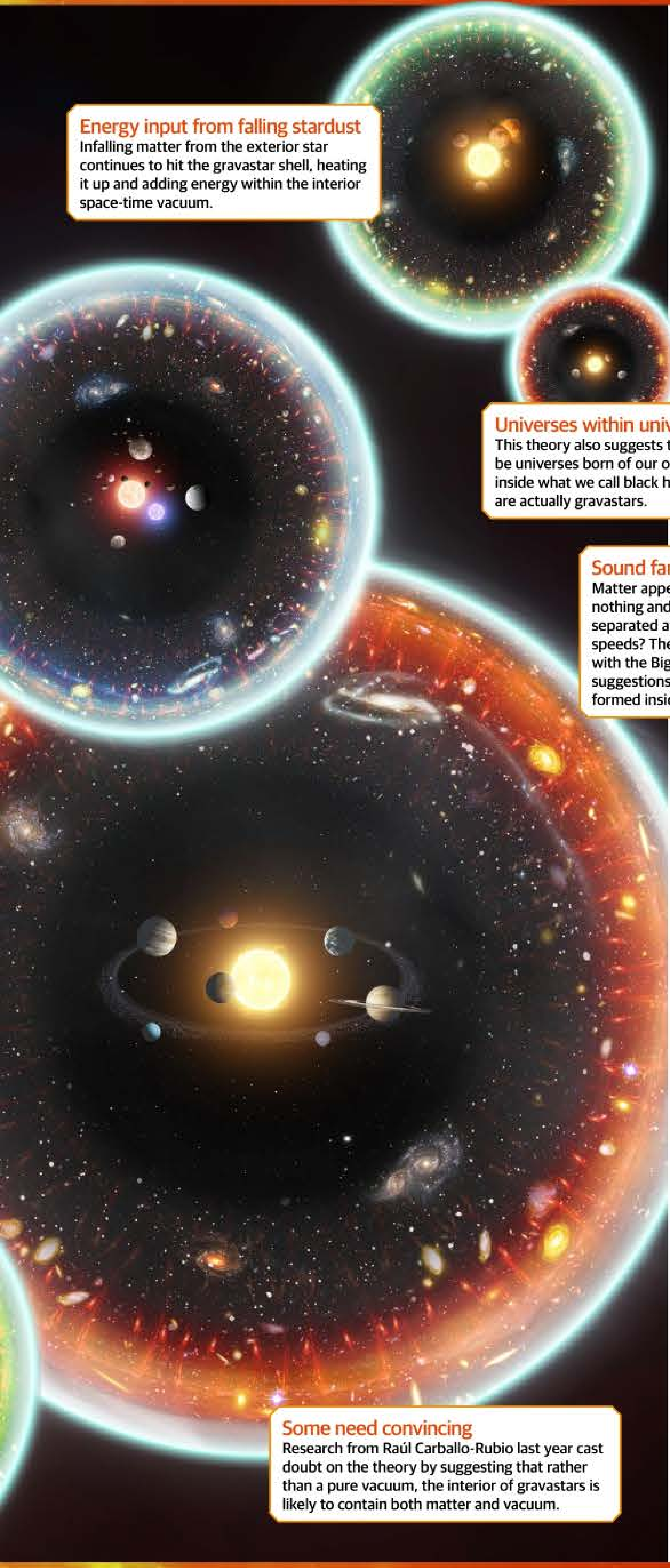
Taking it to the grave

Hawking radiation showed black holes should give out low levels of radiation. This also highlighted they are losing mass and will eventually die, taking any trapped information with them.

Leaking information

This paradox can be avoided by removing the inescapable singularity with a less compact gravastar vacuum bubble which could allow information to leak out over time.

© NASA; Tobias Roetsch



Energy input from falling stardust
Infalling matter from the exterior star continues to hit the gravastar shell, heating it up and adding energy within the interior space-time vacuum.

Universes within universes
This theory also suggests there may be universes born of our own universe inside what we call black holes but which are actually gravastars.

Sound familiar?
Matter appearing out of nothing and then being separated at increasing speeds? The similarity with the Big Bang led to suggestions our universe formed inside a gravastar.

Some need convincing
Research from Raúl Carballo-Rubio last year cast doubt on the theory by suggesting that rather than a pure vacuum, the interior of gravastars is likely to contain both matter and vacuum.

> "Differences between classical black holes and gravastars are profound, but not easily spotted"

singularities, both from gravitational collapse inside black holes, and also in cosmology with the Big Bang. Mazur and Mottola took these observations one step further, while the replacement of classical black holes with gravastars came with the added bonus of a repulsive force to account for our universe's apparent expansion.

As you may have guessed the paper's reviewers had a few questions, and critics pointed out that they were unable to underpin their gravastar with the equations to explain its formation or ongoing dynamic behaviour.

"We didn't know how to do it so we did the simplest thing first: construct a static, spherically symmetric solution that is just sitting there, without telling you how it got there," explains Mottola.

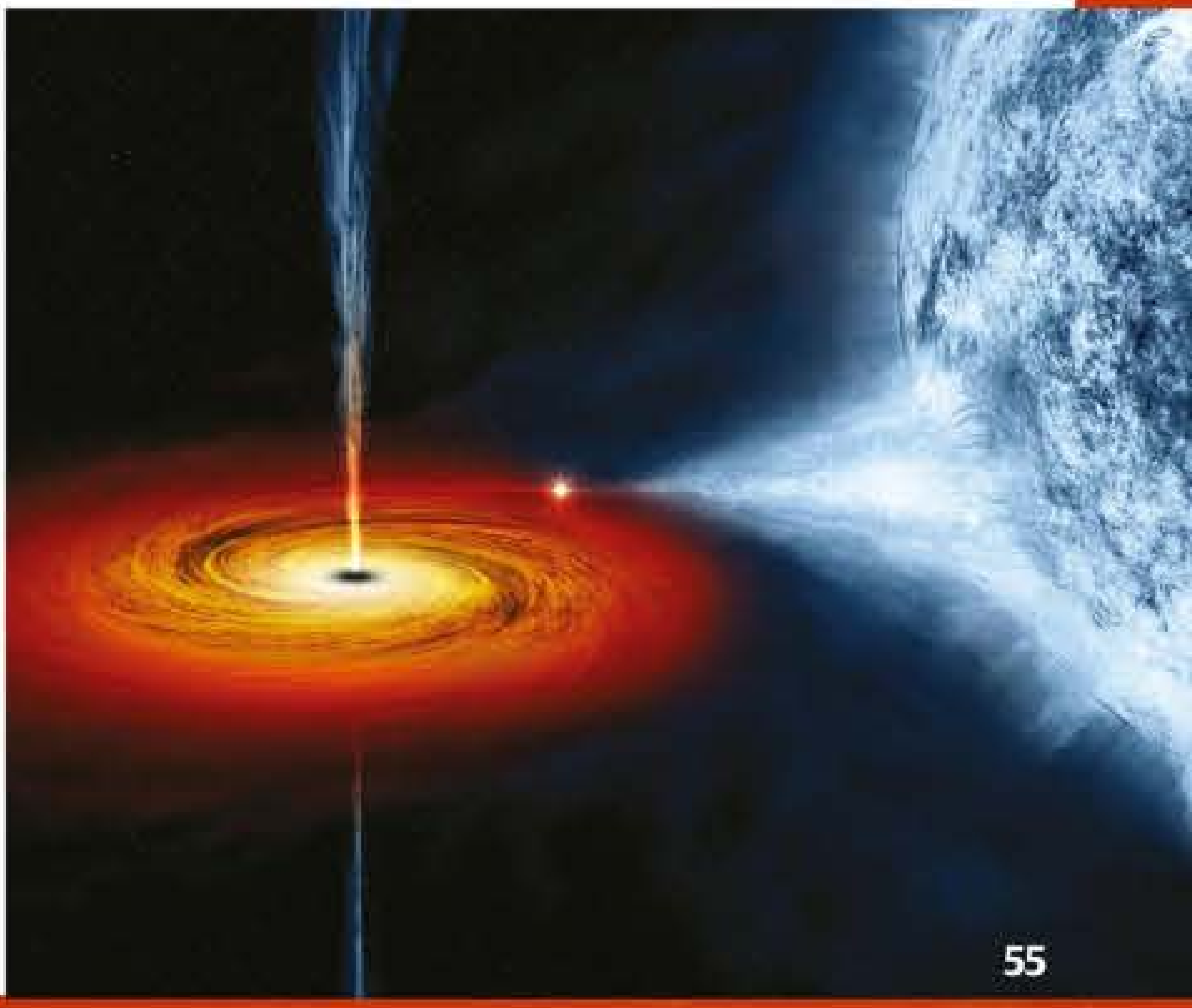
They did eventually get a version of the paper published in 2004 but, after dealing with referees for several years, both were happy to leave it there. "We were tired of fighting," admits Mottola.

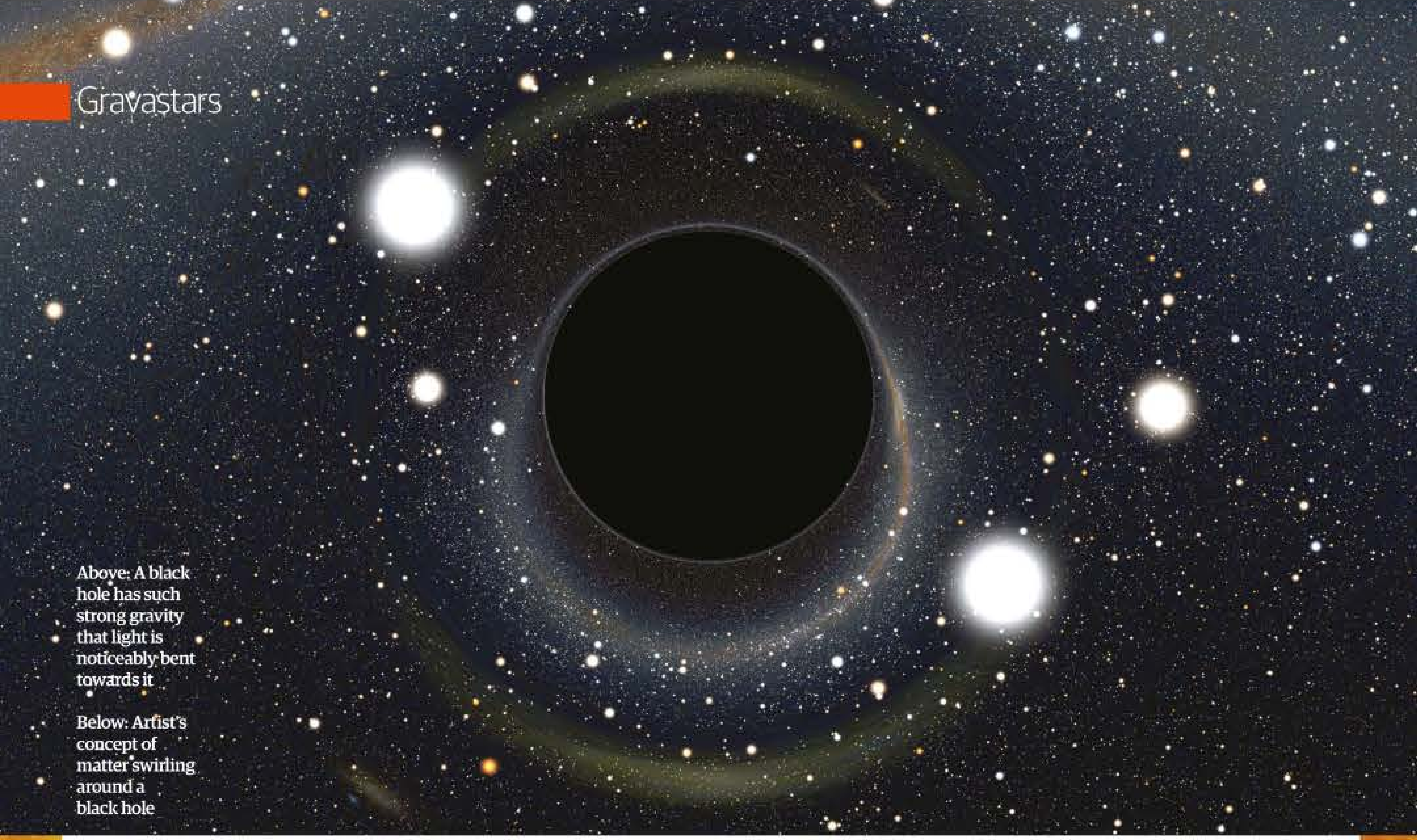
However, they couldn't leave it alone completely. And others didn't either. Theoretical work progressed developing models of more realistic, slowly rotating gravastars that could accrete matter, as well as working out what the observational consequences of this behaviour might be.

"The development of the theory has been slow. We have received criticism and I would accept and agree with the criticism," Mottola continues. Part of the reason for the slow progress was the difficulty in combining theoretical work with observational data.

The differences between classical black holes and gravastars with their solid surface are profound, but not easily spotted. If either object is just sitting there minding its own business there will be no clues as to which theoretical object you are looking

Below: Cygnus X-1 is one of the most likely black hole candidates found so far with a mass of 14.8-times that of the Sun unaccounted for in observations. It is part of a binary pair and is believed to be pulling matter off its companion





Above: A black hole has such strong gravity that light is noticeably bent towards it

Below: Artist's concept of matter swirling around a black hole

at - or not looking at in this case. Just like black holes the compact, intense gravity of a gravastar means any light from it would be deflected by the gravitational field so that it would never reach us.

However, hopes have been raised by theoretical hints that the behaviour of a black hole-gravastar candidate should differ in a way that could be detected when agitated.

"You have to ping it somehow, hit it with something, accrete matter onto it or collide it," says Mottola, though more theoretical work on the gravastar surface is required before we can really start looking in detail.

A more immediate possibility comes from collisions. In 2015 the Laser Interferometer Gravitational-Wave Observatory (LIGO) observed the first direct gravitational-wave signal from what was interpreted as the merger of two black holes. While the scientific world celebrated a stunning vindication of Einstein's theory 100 years later, fans of gravastars were querying the source of these 'ripples' in the fabric of space-time. Mottola believes the low quality of the data leaves enough doubt for alternative interpretations to hold weight. So could the LIGO result really be evidence of gravastar mergers instead? "It could be," he suggests.

> "You would have to overturn a big part of cosmology and inflation and the Big Bang" **Emil Mottola**

With the poor quality of those first datasets we may never know for sure. Instead the hope is that better measurements of future events could allow scientists to eavesdrop on the resulting colliding forces to differentiate between a black hole and gravastar merger.

This hope is encouraged by a particular prediction from gravastar theoretical models - a phenomenon known as gravitational echoes. Simulations of black hole mergers suggest gravitational-wave bursts quickly die out. However, gravastar models see gravitational waves bouncing around inside them and leaking out over a series of progressively weakening spurts. This search should be further aided by the possibilities of multi-messenger studies which observe the same event simultaneously in gravitational waves and across the electromagnetic spectrum.

For the moment Mottola is focusing on tightening up those accretion models. However, for Carballo-Rubio the focus is on the birth of these objects. "How you form this gravastar rather than the gravastar's properties themselves might be the best angle to try and test this observationally," he says.

But what about that original speculation that our universe might exist within a gravastar? Mottola remains positive but cautious. "I would think it is very likely something of that kind is eventually going to be correct," though he admits it is "immature" to talk about the cosmological implications of gravastars when our theoretical understanding of these objects within our own universe is still so incomplete.

Carballo-Rubio is less convinced such a grand idea is worth pursuing at all. His own work, published in early 2018, suggested that rather than a pure vacuum, the internal composition of gravastars is more likely to be a combination of matter and vacuum polarisation. "There is no longer a clear relation between the internal geometry and cosmological solutions," he explains.

For Mottola on the other hand, there are perhaps pragmatic and scientific reasons to focus his energies on the gravastars residing inside, rather than outside our universe. "You would have to overturn a big a good part of cosmology and inflation and the Big Bang, and I am sure that would be even more controversial. But this is not totally off my mind," he concludes.

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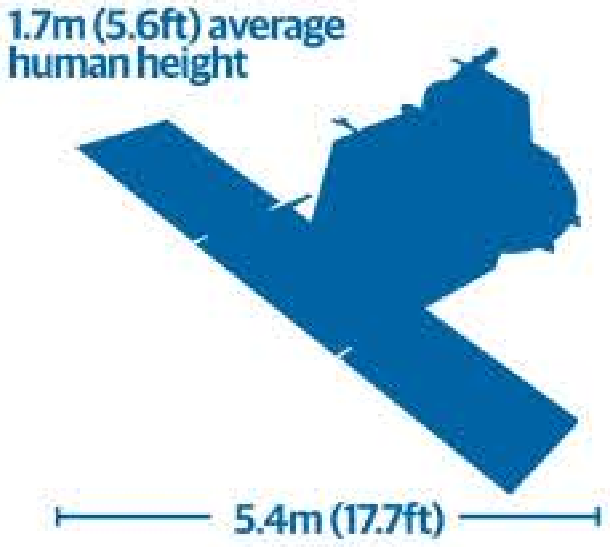
USER MANUAL

Mangalyaan

India's first Mars orbiter, also known as the Mars Orbiter Mission, defines 'cheap and cheerful' in space exploration

THE SPECS

Launch: 5 November 2013
Rocket: Polar Satellite Launch Vehicle C25 (PSLV-C25)
Target: Mars
Operator: Indian Space Research Organisation (ISRO)
Estimated cost: £47 million (4.5 billion Indian Rupees)
Time in space: Over four years
Distance from Earth: 225 million kilometres (140 million miles)



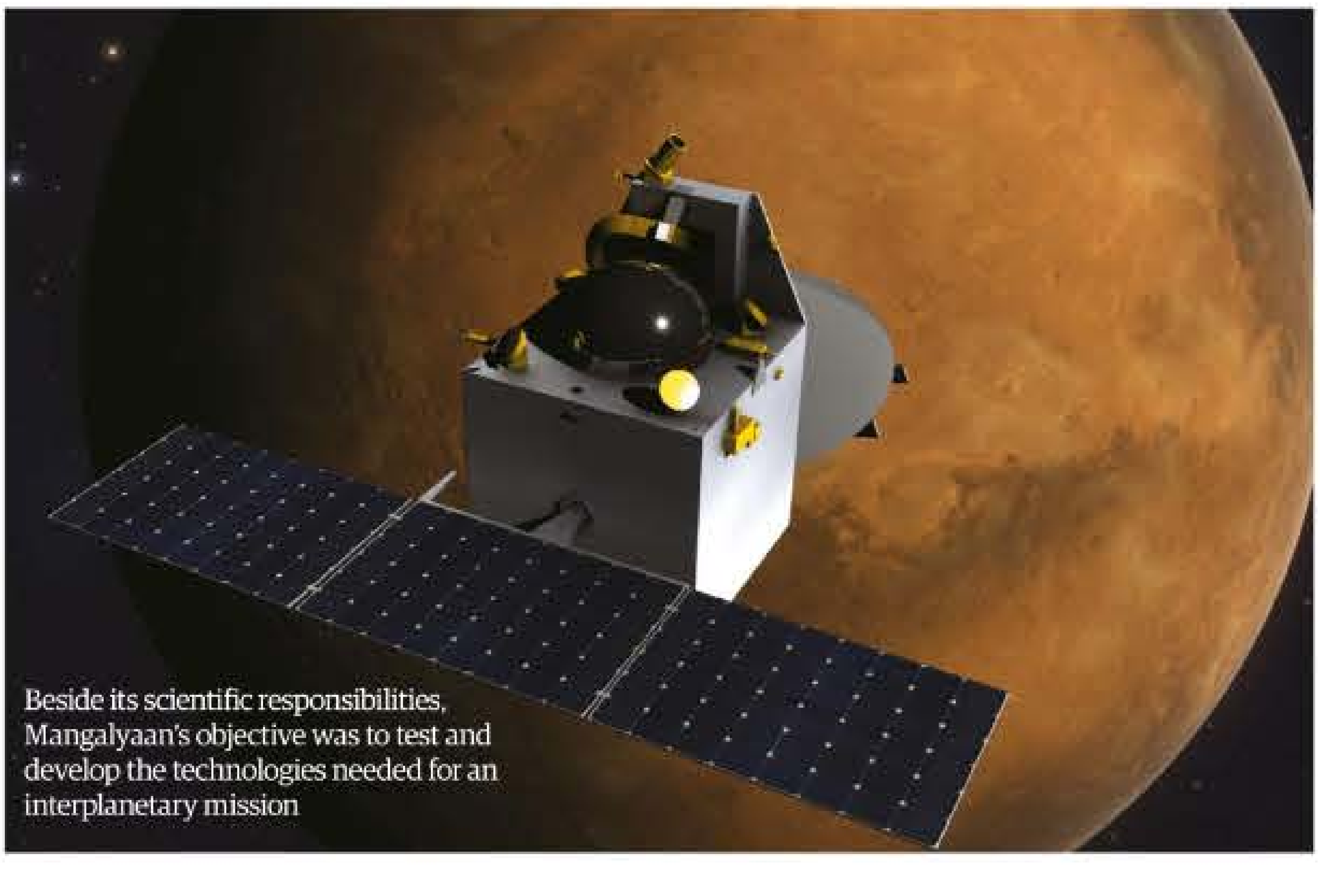
On 5 November 2013 the ISRO launched its maiden interplanetary mission to Mars. This was an incredible feat not only for India, certifying its position as a serious presence in space, but for space travel, proving that a task like this can be completed on a relatively cheap budget.

At the tip of a PSLV-C25 rocket, carrying 12 tonnes of propellant, was India's Mars Orbiter Mission, also referred to as Mangalyaan, which means 'Mars-craft' in Hindi. After completing the 667-million-kilometre (414-million-mile) journey through space over the course of just over ten months Mangalyaan was inserted into the orbit of Mars, and India rejoiced at its first interplanetary craft being successful. Although the spacecraft's primary objective was to explore and study the surface of the Red Planet, it also aimed to develop and test the technologies needed for a interplanetary mission and prove it could be done - hence the excitement upon its successful arrival. Its scientific payload was equipped with five instruments keen to send back vital data from millions of miles away.

Mangalyaan has received much praise due to its efficient design and cost-effective execution. The mission only had a total cost of £47 million ($74 million) which, considering that the blockbuster film *The Martian* had a budget of £82 million ($108 million), shows it can actually be cheaper to go to Mars than make a film about it! In fact, NASA's MAVEN orbiter that arrived at Mars around the same time cost over 11-times as much. This incredible cost efficiency was achieved in part by keeping the spacecraft small and light, with the scientific payload weighing about 15 kilograms (33 pounds). A light payload means less money spent on fuel for takeoff and the journey itself. A lot of the cost saving was due to the hard work in India, as here labour costs are lower than their American counterparts and the country also prioritises home-grown components and technologies.

Since Mangalyaan arrived at Mars it has consistently been busy at work and has surpassed its planned six-month lifetime by an impressive margin. However, during this time the orbiter has encountered some 'blackouts' and 'whiteouts'. A blackout occurs when Mars is behind the Sun from Earth's position, making it impossible to interact with the orbiter for a time, whereas a whiteout occurs when Earth is between the Sun and Mars and there is too much radiation to communicate. Luckily Mangalyaan had the autonomy to successfully survive both of these scenarios.

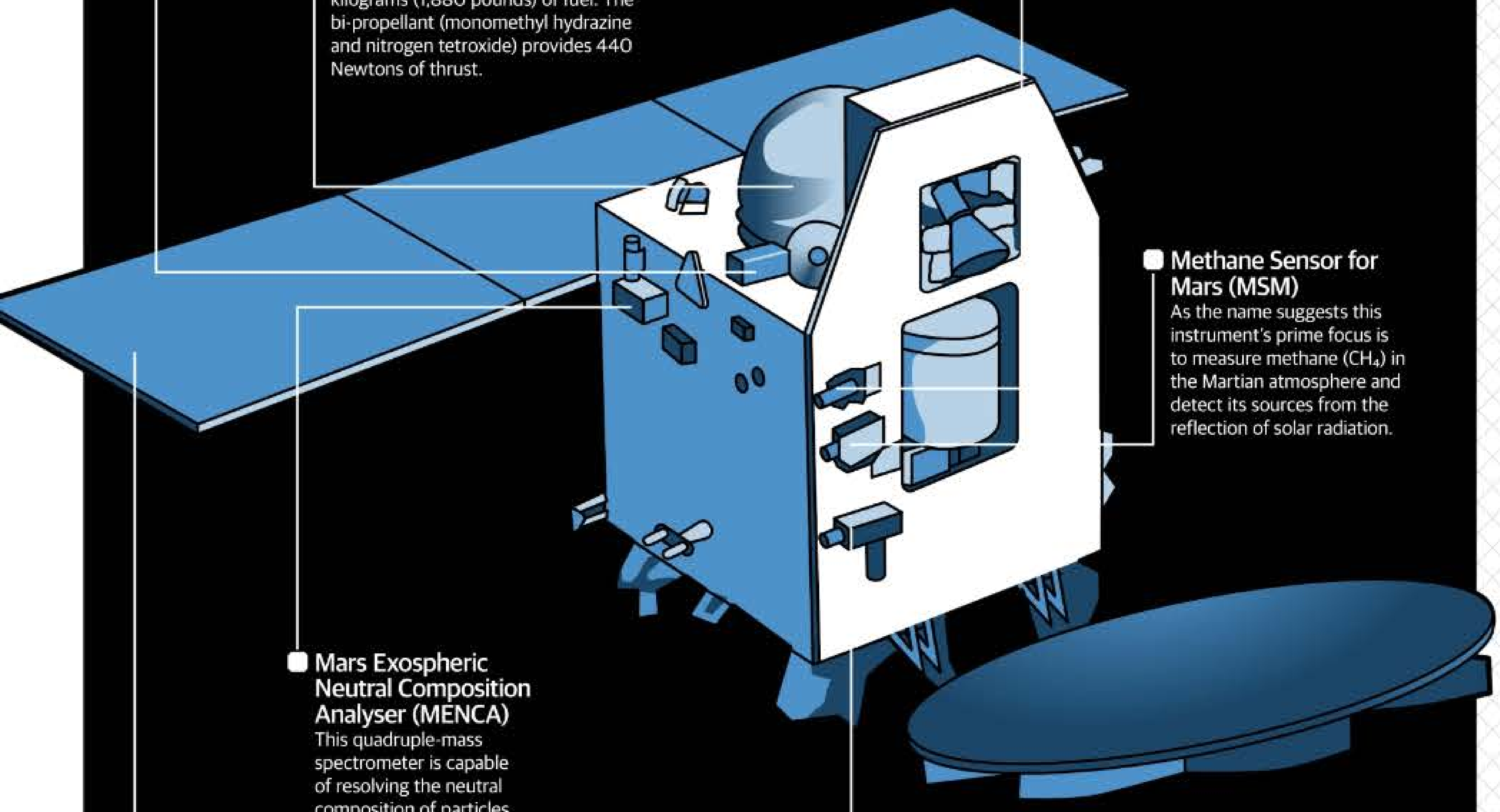
The five instruments on board the Indian explorer have sent back some tremendous results. There are yet to be any groundbreaking discoveries, but the NASA orbiters and rovers that have made


Beside its scientific responsibilities, Mangalyaan's objective was to test and develop the technologies needed for an interplanetary mission

The Prime Minister of India, Narendra Modi, was present at the orbital insertion of Mangalyaan around Mars

Anatomy of a Martian Orbiter

Similar to the structure of India's lunar mission, Chandrayaan-1, Mangalyaan is still operating in orbit around Mars



Lyman-Alpha Photometer (LAP)
The LAP will determine the relative abundances of deuterium and hydrogen in the upper atmosphere of Mars. This will help determine the escape rate of water from the planet.

Mars Colour Camera (MCC)
The MCC provides important tri-colour images of the surface and moons of Mars. This is important in observing events, gaining compositional information and providing contextual images to other instruments' data.

Propellant tank
With a capacity of 390 litres, the spacecraft was launched with 852 kilograms (1,880 pounds) of fuel. The bi-propellant (monomethyl hydrazine and nitrogen tetroxide) provides 440 Newtons of thrust.

Methane Sensor for Mars (MSM)
As the name suggests this instrument's prime focus is to measure methane (CH_4) in the Martian atmosphere and detect its sources from the reflection of solar radiation.

Mars Exospheric Neutral Composition Analyser (MENCA)
This quadruple-mass spectrometer is capable of resolving the neutral composition of particles in the range of 1 to 300 atomic mass units.

Solar array
Three solar panels measuring 1.8 by 1.4 metres (6.0 by 4.6 feet) provide 840 Watts of power while in orbit around Mars.

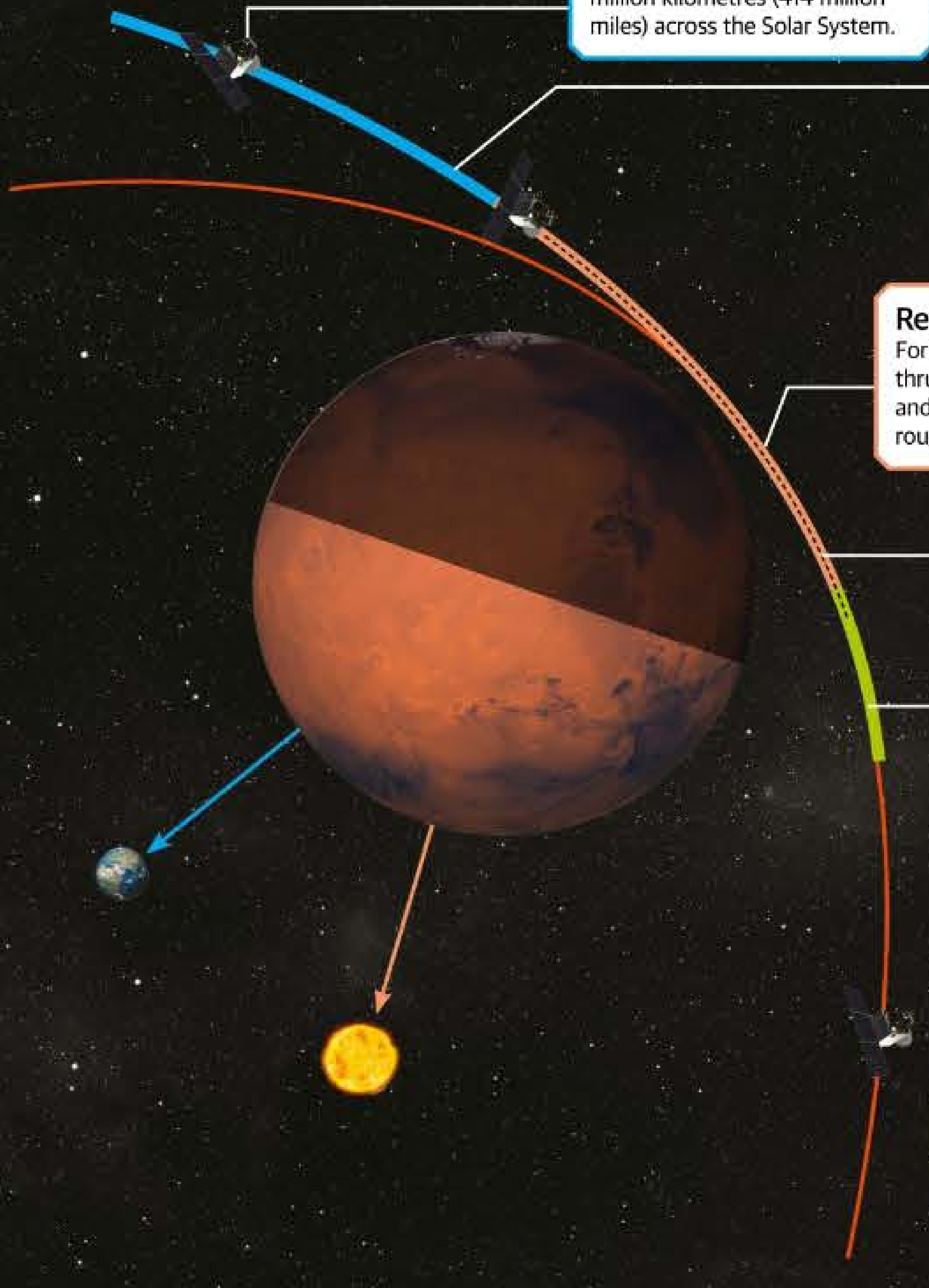
Thermal Infrared Imaging Spectrometer (TIS)
During both day and night on Mars TIS can observe thermal emissions to map the surface composition and mineralogy of Mars and also monitor atmospheric carbon dioxide and turbidity.

Mars and its north pole were imaged at a distance of 55,000 kilometres (34,000 miles) away using the Mars Colour Camera (MCC)

these have a much more extensive range of instruments and are of a higher calibre - but also a much higher cost. Mangalyaan's Methane Sensor for Mars (MSM) has been measuring the amount of methane in the Martian atmosphere. Unfortunately the levels of methane on Mars are actually beyond the sensitivity of the MSM, so no methane was spotted. However, it has constructed reflectance maps of Mars with superb detail.

Other instruments on board include the Mars Colour Camera (MCC) which has 16 different modes of exposure and has produced some magnificent images of Mars and its moons as a result. The Mars Exospheric Neutral Composition Analyser (MENCA) has been carefully studying the uppermost region of the planet's atmosphere, known as the exosphere, and it holds the answers as to why there is essentially no atmosphere and what happened

How to... Get into Martian orbit



Brace for arrival
Mangalyaan had journeyed for over ten months, travelling 667 million kilometres (414 million miles) across the Solar System.

Reorienting Mangalyaan
Upon approach the craft needs to readjust its position so that the thrust vector can be made effective before the engines fire.

Reducing the speed
For 24 minutes the liquid engine and eight thrusters are fired to slow down the spacecraft, and ends with the craft placed into an orbit roughly 970 kilometres (600 miles) above Mars.

Blackout in communication
For 20 minutes during this engine burn Mars is stopping communications between the spacecraft and Earth. However, the scientists have prepared the spacecraft for this blackout in order to continue operations.

Fixing into position
After the burn the spacecraft is reorientated so that the Medium Gain Antenna faces towards Earth.

> "The longevity and success of this mission has surprised many all over the world"

in Mars' past to make this so. MENCA provided the first measurements of the low-latitude exosphere in its evening time as well as the discovering 'hot' Argon in the exosphere. The Thermal Infrared Imaging Spectrometer (TIS), coupled with Mangalyaan's elliptical orbit, has provided some clear infrared maps of Mars, measuring its thermal emission. Lastly, the Lyman-Alpha Photometer (LAP) is the first Indian space-borne absorption gas-cell photometer that measures the amount of hydrogen and deuterium in the atmosphere.

This spacecraft is still being carefully monitored from the Spacecraft Control Centre at the ISRO Telemetry, Tracking and Command Network (ISTRAC) in Bangalore, the capital of the Indian state Karnataka, with support from the Indian Deep Space Network (IDSN) antennae at Byalalu, Karnataka, India. The longevity and success of this mission has surprised many all over the world, and in terms of Indian space exploration this is a huge stepping stone for missions to come.

TOP TECH

Mars Colour Camera

During its four-year mission, Mangalyaan's MCC has acquired more than 980 images using its 16 different exposure modes. Specifically, the camera incorporates an electro-optical sensor that images the Martian surface in three colours, red, green and blue, and offers a spatial resolution that varies between 20 to 4,000 metres (66 to 13,133 feet).

The main science objectives of this camera are to unveil the secrets of Mars' surface features, and monitor the dust and clouds around it. One of its key achievements was spotting that the clouds over different mountains, for example Olympus and Elysium Mons, have a unique morphology.

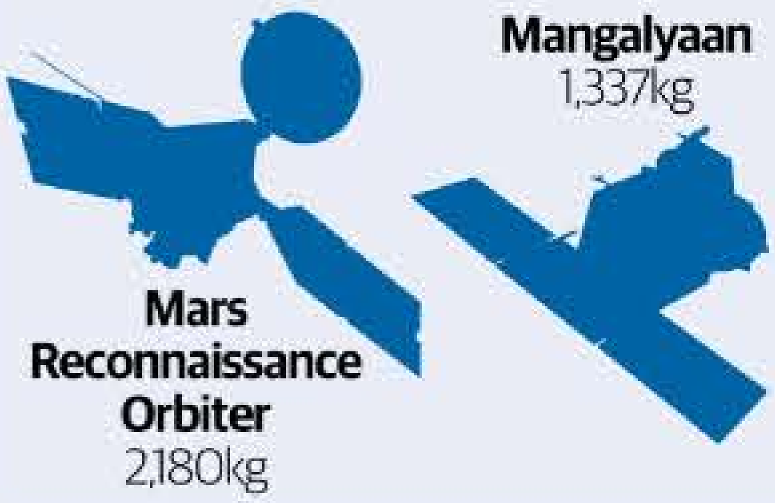
Head-to-head

Mangalyaan vs Mars Reconnaissance Orbiter

NASA's Mars Reconnaissance Orbiter (MRO) arrived at Mars on 10 March 2006, giving it over eight-years more experience than Mangalyaan. It arguably has a more impressive instrumental suite than the Indian spacecraft.

MRO carries six scientific instruments, having one more than Mangalyaan, but it is the High Resolution Imaging Science Experiment (HiRISE) camera which has continued to provide spectacular high-resolution images of the Martian surface.

Although MRO seems to be better in terms of quality, Mangalyaan is significantly cheaper, being roughly ten-times less expensive than the MRO.



Vital statistics

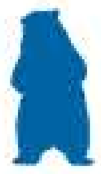
366km = Almost 17-times the elevation of Olympus Mons above Mars

Its closest point to Mars

4 Years = This is eight-times longer than the original plan for the mission

Time Mangalyaan has been at Mars

1.5mtr = The average height of an adult brown bear



The dimensions of the spacecraft

15kg = Roughly one-tenth the mass of NASA's MRO scientific payload

The mass of Mangalyaan's payload

4th = The other three are NASA, the Soviet space agency and the ESA.

space agency to reach Mars

HOW TO...

Build a cheap Martian orbiter

1 Choose a short time period

Mangalyaan only took 15 months to build which, when you take into consideration that NASA's MAVEN spacecraft took five years, saves costs in several departments of which the greatest cost is the people.

2 Use lightweight materials

The orbiter weighs only 1,337 kilograms (2,950 pounds) even with the five scientific instruments on board. This means that less fuel is needed to take it into space, also making the spacecraft more fuel efficient once there.

3 Make only one model

To avoid unnecessary costs the ISRO only constructed one physical model of Mangalyaan. This saved costs on unnecessary materials and labour time on models that wouldn't end up being used during the main mission.

4 Use home-made technologies and components

The ISRO utilised home-made materials as much as possible. Although it didn't rule out the use of imports, it stated that home-grown components and technologies were made priority.

© ISRO; K. M. Gill

The start of the journey
Before Carlos sets off in his spaceship, destined for Earth's nearest star system Alpha Centauri at a distance of four light years away, he and Martin synchronise their watches. In this scenario both Carlos and Martin are in the same frame of reference, experiencing the same motion of time and space and time dilation has yet to interfere.

Instant Expert

Time dilation

What happens to time when travelling at extreme speeds? **All About Space** has asked a scientist to break it down in terms of twins

Martin and Carlos are identical twins. Well, almost. While Martin is a medical doctor, Carlos is an astronaut about to travel to Alpha Centuari, the nearest star system to our own, at speeds nearing that of light. Just before takeoff Martin and Carlos synchronise their watches, and Carlos reminds Martin that Einstein's theory of special relativity predicts 'time dilation', that is, that watches moving at a constant high speed appear to tick at a slower pace.

This gets Martin thinking... With Carlos moving rapidly his watch will run slower, which means that he will be younger upon his return! But from Carlos' perspective Martin will be the one moving at high-speed, so Martin's watch will appear to run slower, and so it is Martin who should stay younger.

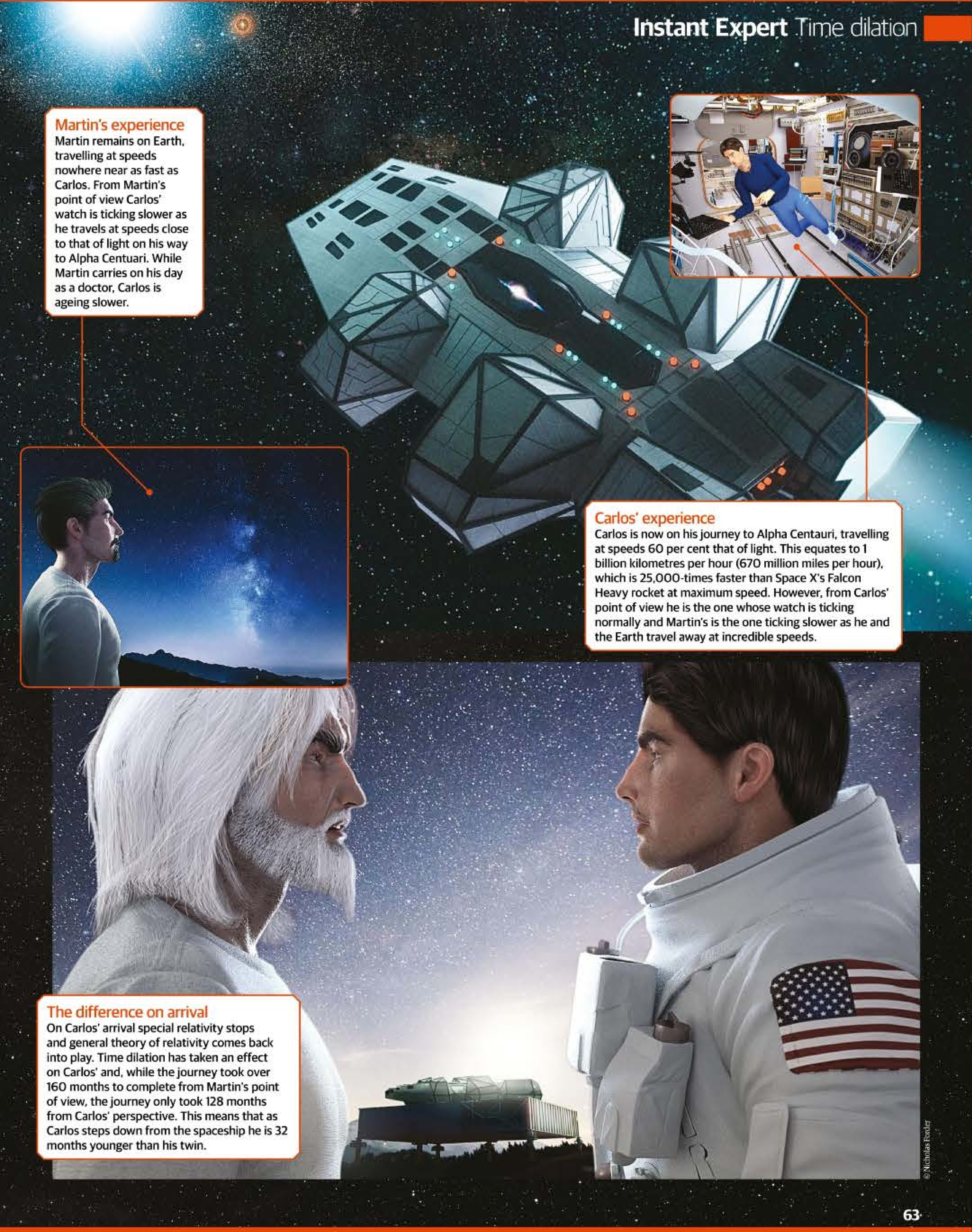
This is the famous 'twin paradox', which is not really a paradox! How is this possible? First, even in relativity the time and space intervals assigned by observers to pairs of events – like two successive ticks of a clock – do not necessarily match. There is an unambiguous map between the coordinates of events seen by different observers in relative motion. The key point in our example is that the events defining two successive ticks in Martin's clock – which happen at the same point in Martin's reference frame – do not happen at the same point in space from Carlos' perspective, because he sees Martin's clock in motion. So Carlos cannot compare directly the ticks of Martin's watch to the ticks of his own watch, because they take place at different points in space.

But surely they could compare the ticks when they happen at the same point, for example just before and just after the trip?

For Carlos' ship to return it has to change course in the middle, which implies the action of a force, and then special relativity does not apply. In this case it is Einstein's general theory of relativity that tells us that Carlos will stay younger. Sorry, Martin!

BIO
Dr Carlos Tamarit

Tamarit is a physicist at the Technical University Munich, Germany, who focuses on the theoretical physics of the early universe. His extensive knowledge in particle physics makes him more than qualified to explain the complexities and stranger side of the cosmos.



Martin's experience

Martin remains on Earth, travelling at speeds nowhere near as fast as Carlos. From Martin's point of view Carlos' watch is ticking slower as he travels at speeds close to that of light on his way to Alpha Centuari. While Martin carries on his day as a doctor, Carlos is ageing slower.

Carlos' experience

Carlos is now on his journey to Alpha Centauri, travelling at speeds 60 per cent that of light. This equates to 1 billion kilometres per hour (670 million miles per hour), which is 25,000-times faster than Space X's Falcon Heavy rocket at maximum speed. However, from Carlos' point of view he is the one whose watch is ticking normally and Martin's is the one ticking slower as he and the Earth travel away at incredible speeds.

The difference on arrival

On Carlos' arrival special relativity stops and general theory of relativity comes back into play. Time dilation has taken an effect on Carlos' and, while the journey took over 160 months to complete from Martin's point of view, the journey only took 128 months from Carlos' perspective. This means that as Carlos steps down from the spaceship he is 32 months younger than his twin.

© Nicholas Forder

WHEN NEUTRON STARS COLLIDE

THE KILONOVA STORY

A pair of neutron stars that merged over a billion light years away could have created an unexpected cosmic relative of a past gravitational wave

Reported by Lee Cavendish

The universe is full of enormous cosmic events that produce vast amounts of energy and elements that are spread throughout the cosmos. Some of these take millions of years, for example observing a star slowly deplete its fuel before exploding, resulting in a supernova. On the other hand, some take place in a fraction of a second, like the merging of neutron stars that creates gravitational waves. The latter are an enigma to astronomers, and our understanding of them has only evolved significantly in the last year or so with the Laser Interferometer Gravitational-Wave Observatory, or LIGO as it's more commonly known, in the United States and the Virgo interferometer in Italy.

Just recently, astronomers found a peculiar signal that they believe to be from two colliding neutron stars. This event was originally spotted as a rapid emission of light in the gamma-ray section of the electromagnetic spectrum, giving it the name GRB - an abbreviation for gamma-ray burst 150101B. This rapid burst of light was first spotted by the Gamma-ray Burst Monitor aboard NASA's Fermi Space Telescope on 1 January 2015. Follow-up observations were made using a whole host of telescopes over a series of wavelengths, including NASA's Neil Gehrels Swift Observatory and Chandra X-ray Observatory, both in space, and the 6.5-metre (21-foot) Magellan Telescope at the Las Campanas Observatory in Chile.

"GRB150101B was discovered by NASA's Fermi mission, but its position in the sky was not known very well and we could not perform any other observations because we did not know where to look," Dr Eleonora Troja from NASA's Goddard Space Flight Center in Greenbelt, Maryland, United

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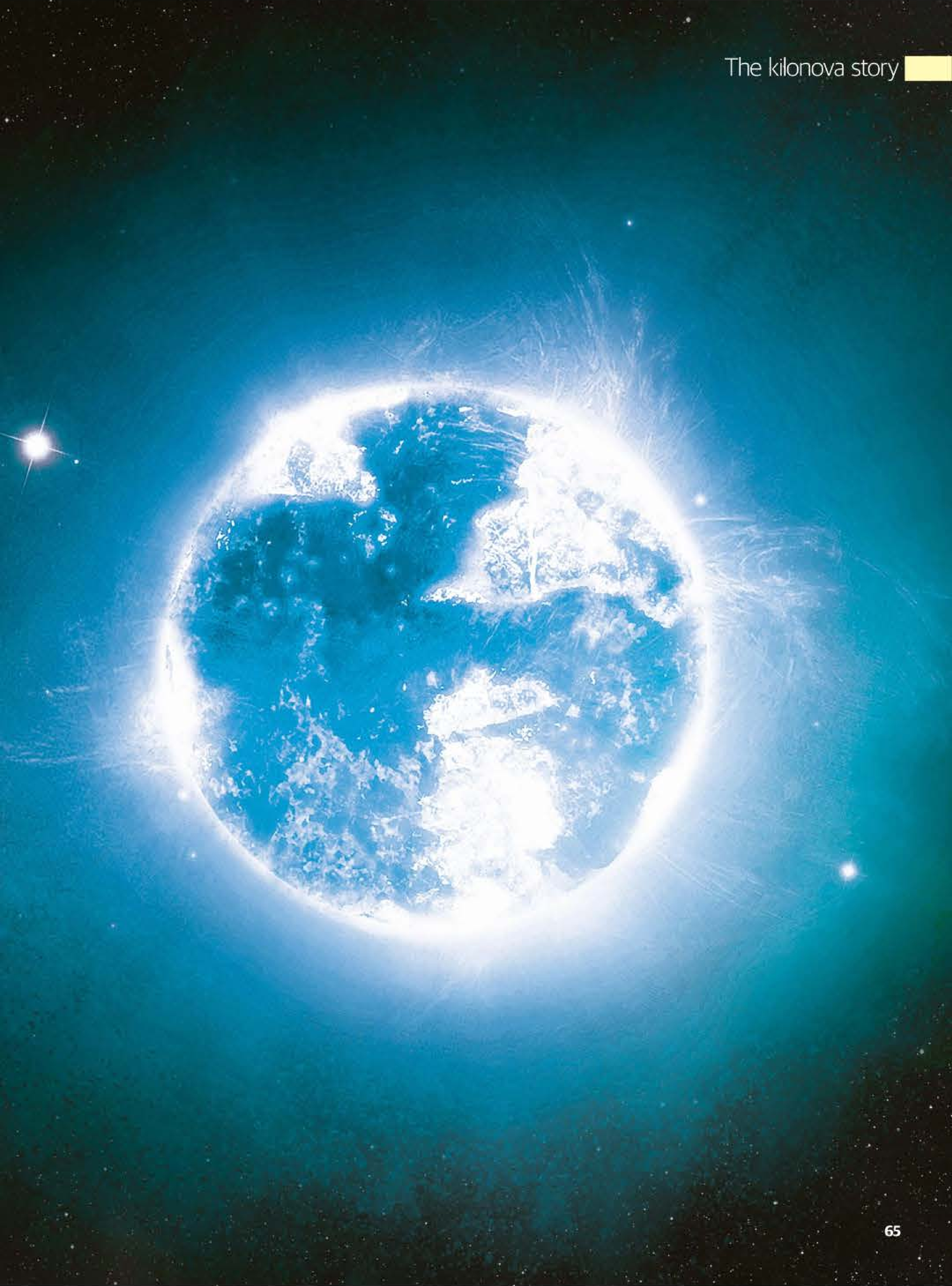
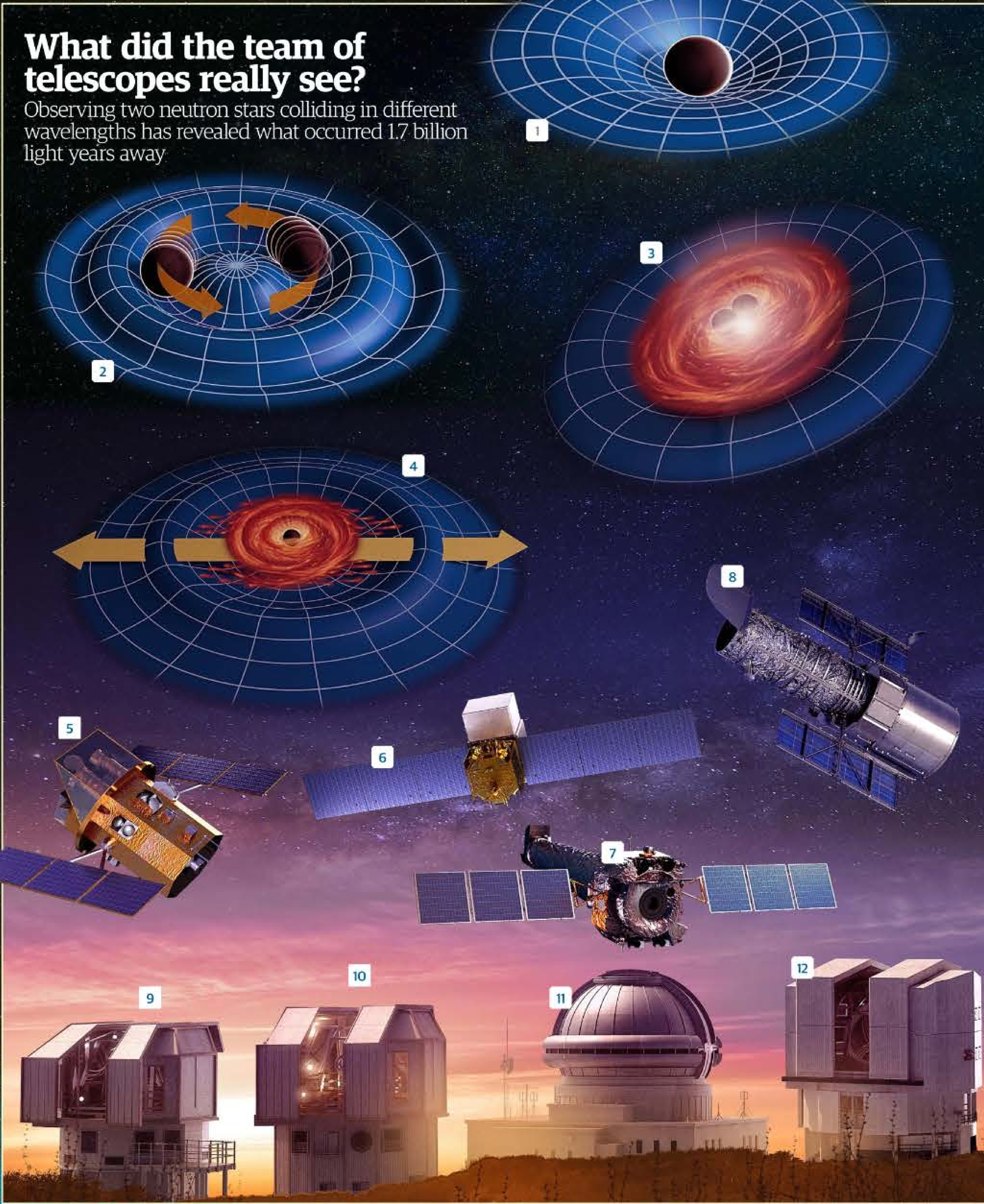


What did the team of telescopes really see?

Observing two neutron stars colliding in different wavelengths has revealed what occurred 1.7 billion light years away



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1 A neutron star's power

Neutron stars are incredibly dense and small, with up to 2.1-times the mass of the Sun packed into a star the size of a city. This makes a deep dent in space-time.

2 Stuck in gravity's dance

When binary neutron stars are intertwined in a gravity-induced dance, gravitational waves are spread through space-time, such like the ripples caused by throwing a stone into a pond.

3 When two neutron stars become one black hole

As the orbits shrink and energy is lost, the merger is imminent. As the stars merge a flurry of the highest energy is released as a kilonova begins, and this was spotted by NASA's Fermi satellite on 1 January 2015.

4 The aftermath of energy

After the merger the team of telescopes were able to observe X-ray and optical emissions of the black hole, kilonova and its jets. The blue optical light and a long-life X-ray emission gave away its identity.

5 Fermi Space Telescope

Fermi was the first to spot the signal. It lasted 12 milliseconds – enough to catch the attention of the astronomers.

6 Neil Gehrels Swift Observatory

Swift was able to pinpoint the location of GRB150101B as it has a sharper view than its companion, the Fermi telescope.

7 Chandra X-ray Observatory

Chandra was crucial in resolving the presence of two nearby sources and characterising their properties.

8 Hubble Space Telescope

The images of the galaxy that accommodated GRB150101B taken by Hubble struck a similar resemblance to the host galaxy of GW170817.

9 Magellan Telescope

By using Magellan's Inamori-Magellan Areal Camera and Spectrograph, or IMACS, optical light from the burst was detected 36 hours later.

10 Discovery Channel Telescope

Photometric and spectroscopic analysis was made using the Discovery Channel Telescope, which can observe in near-ultraviolet to far-infrared.

11 Gemini South Telescope

Gemini South showed that the source exhibited the usual dominant afterglow component after ten days and that the kilonova had already faded.

12 Very Large Telescope

The VLT imaged the source two days after the GRB detection in near-infrared using its High Acuity Wide field K-band Imager (HAWK-I).

A kilonova produces many exotic elements, such as gold, platinum and uranium

> "All neutron star mergers produce gravitational waves; this is something we're extremely confident about" **Dr Van Eerten**

States, and the University of Maryland at College Park (UMCP) tells **All About Space**. "Luckily the signal was also caught by NASA's Neil Gehrels Swift Observatory. Swift has a sharper view than Fermi and clearly pinpointed the GRB's position in the sky. This allowed astronomers to use other telescopes and observe that region of the sky in other wavelengths such as radio, optical and X-ray.

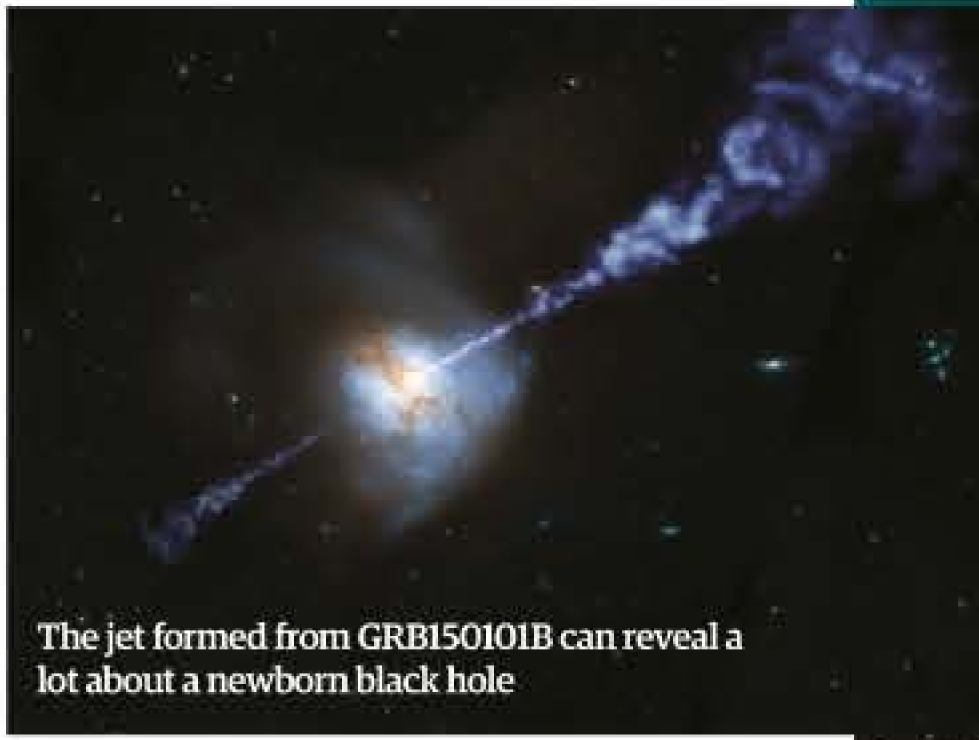
"The Magellan telescope detected the optical light 36 hours later, whereas NASA's Chandra X-ray Telescope saw its X-ray afterglow eight days after the gamma-ray burst was seen for the first time." This chain of events was also helped by data taken by the Hubble Space Telescope; the Discovery Channel Telescope (DCT), a 4.3-metre (14.1-foot) telescope in Arizona, United States; the European Southern Observatory's Very Large Telescope at the Paranal Observatory in Chile and the Gemini South telescope also situated in Chile at Cerro Pachón.

What led to this investigation, though? What made astronomers look at the signal and think that this warranted extra observation time using multiple telescopes? The answer to that is explained by a fellow researcher in the study, Dr Hendrik Van Eerten of the University of Bath, United Kingdom.

"The X-ray instrument on board Swift detected a signal that remained unusually steady over a long period of time. This was so unexpected," explains Van Eerten to **All About Space**. "A rapid fade-out, or at least any sort of fade-out, is more usual for 'short' GRBs – the type caused by merging neutron stars. To get a more in-depth observation in the X-rays, with better spatial resolution, the Chandra X-ray telescope was utilised."

The gamma-ray burst exhibited not only had a notably short fade-out, but it was extremely weak as well. In fact, it has one of the lowest energies ever detected by the Swift telescope. Just over a day after the detection follow-up observations were conducted in bright optical and X-ray wavelengths. After such data had been collected and the options ruled out there was only one explanation to this conundrum, and the researchers announced that they had just witnessed the kilonova caused by the merger of two neutron stars 1.7 billion light years away from Earth.

Unlike a supernova – a stellar explosion that signals the end of a star's life – a kilonova has a different process and emits different forms of energy. The most common form of supernova, a Type II, occurs when the star cannot maintain nuclear fusion and causes a collapse of outer material against its solid core, thus exhibiting the explosion that thrusts large amounts of material into the cosmos – this type of explosion can shine with the brightness of 10 billion Suns. What is left behind after a supernova can either become a black hole or a neutron star, which is a star that has



The jet formed from GRB150101B can reveal a lot about a newborn black hole

A neutron star is not much bigger than Munich, Germany, but a teaspoon of the star can weigh as much as the entire human population

a large mass tightly jammed into a sphere that is about the size of a city.

When two of these neutron stars collide they emit vastly greater amounts of energy, and the final bang at the end of its crescendo can result in a gamma-ray burst, which was spotted in GRB150101B. These events are the creators of some of the universe's most exotic and heaviest elements. "It [the ejecta] is so hot, dense and neutron-rich that unstable massive nuclei are formed faster than they can decay. Eventually they do decay to more stable isotopes, just about everything with atomic numbers from about 30 to about 80," explains Dr Geoffrey Ryan of the University of Maryland at College Park (UMCP), United States, to **All About Space**. "You've heard of gold, I'm sure. But there's also iridium, tungsten, silver, palladium, all the way down to rubidium and selenium. Even the lanthanides, like europium, are made."

> "Optical tells us about the kilonova; X-rays tell us about the jet and the newborn black hole" **Dr Eleonora Troja**

The LIGO detectors were not operational during the time of the GRB150101B detection

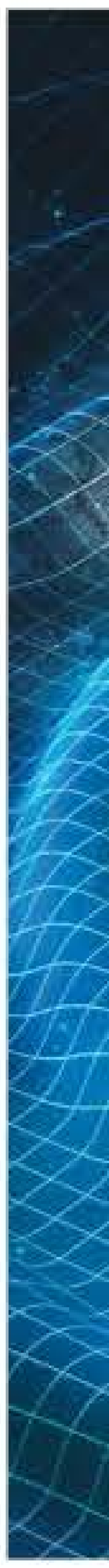
During a kilonova a fast-moving jet of energy is also emitted from the source and is normally firing from both ends of a newly formed black hole, perpendicular to its plane of rotation. "We can study these two, very different events [the kilonova and the jet] because we have the ability to see the sky through different lenses: optical tells us about the kilonova and the production of heavy elements; X-rays tell us about the jet and the newborn black hole," says Troja.

On 17 August 2017 a worldwide fleet of telescopes all turned their heads to the constellation of Hydra to follow up on a gravitational-wave detection made by LIGO and Virgo. It was then that astronomers found the first-ever visible counterpart to a gravitational-wave detection. GW170817 was located 130 million light years from Earth. Astronomers were able to deduce that this event was also the result of two neutron stars merging.

The astronomers involved in the analysis of GRB150101B have claimed that it is a cosmic 'relative' of GW170817. Troja, Ryan and Van Eerten all agree that these two events are remarkably similar and could well be related. The main similarities are the unusually faint and short-lived GRB, but they also both emitted bright, blue optical light which lasted over a period of days - the X-ray emission lasting even longer - and their local environment also strikes a resemblance.

"Both GRB150101B [and GW170817] are dim for gamma-ray bursts, we believe because we are viewing them off-axis, away from the core of the jet. Both are also optically bright," says Ryan. "In the case of GRB150101B, in optical wavelengths it appears brighter than you would expect for the afterglow alone, and the difference is about the brightness expected for a kilonova. Both events also occur in the outskirts of the same type of galaxy: old, luminous, and elliptical."

What appears to be missing though is the detection of the far more valuable gravitational waves. These waves were predicted by Einstein's general theory of relativity over a century ago which states that the most intense events in the universe, such as black holes or neutron stars merging, will create ripples in time and space. The LIGO mission was the first to prove this true with its first detection in September 2015. The Advanced LIGO experiment wasn't fully functional until the month before the first gravitational-wave detection, however, meaning that the detectors missed the chance to view GRB150101B by eight months. But



Quickfire questions with the kilonova discoverer

Dr Eleonora Troja is an associate research scientist in the Department of Astronomy at the University of Maryland, and works primarily at the NASA Goddard Space Flight Center in the Astrophysics Science Division

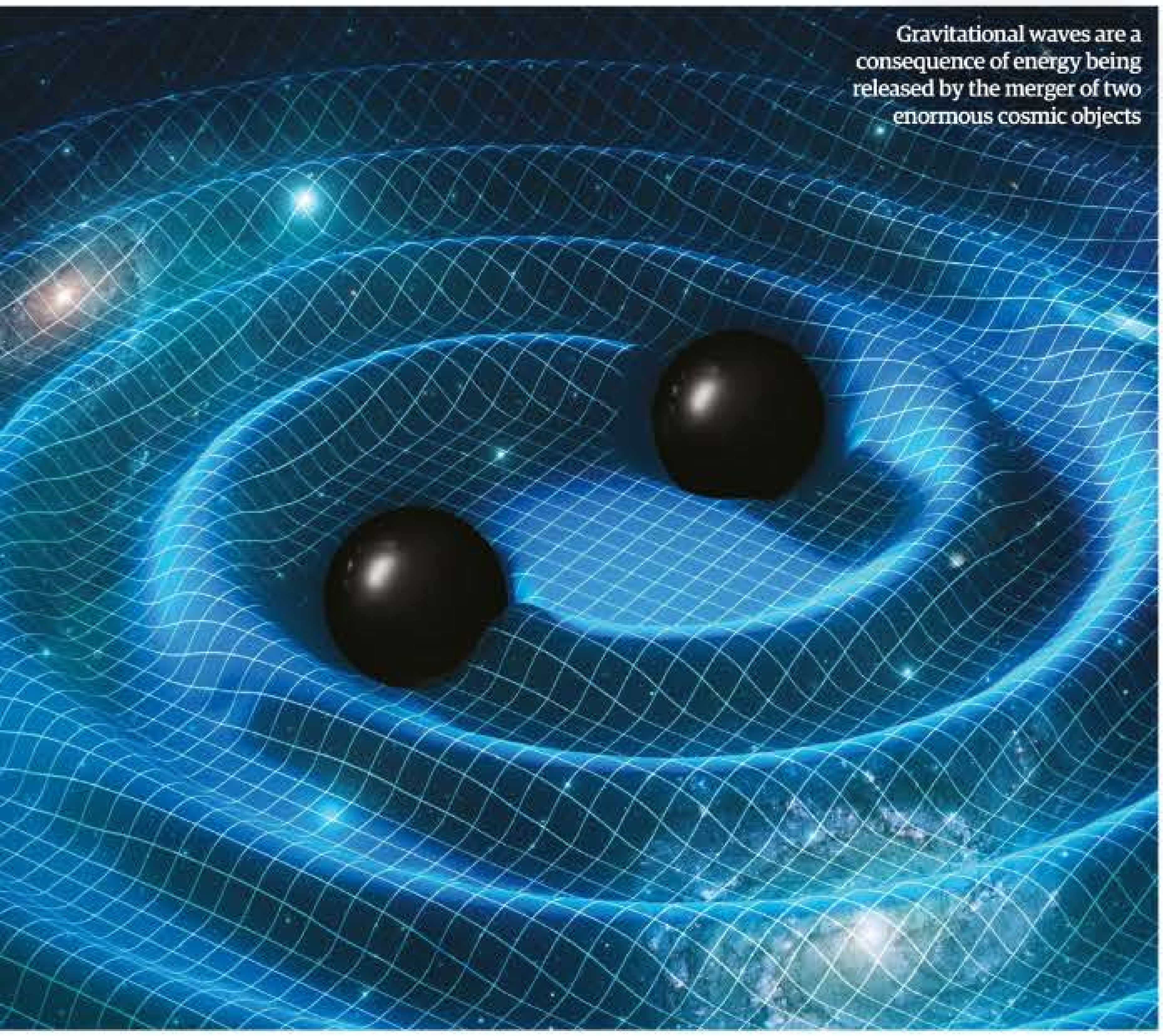
What are the similarities between GRB150101B and GW170817?
We think that in both cases the jet was not pointing toward us, but was slightly tilted. In all previous cases of GRB explosions the jet was always pointing straight toward us, and its light was outshining everything else. It was like someone pointing a flashlight straight into our eyes – we could not see anything else but the bright light.

In GRB150101B and GW170817 the different jets' orientations caused the light to look dimmer for us, and this unveiled the other facets of a neutron star merger, including the kilonova.

What are the differences between the two sources?
GRB150101B was much farther away. A distance of 1.7 billion light years is over 1,000-times farther away than GW170817. Even if LIGO was operational at the time, the gravitational-wave signal from GRB150101B would have been too faint to be detected.

What does this discovery and analysis mean for our understanding for such enormous cosmic events?
It means that GW170817 and its bright kilonova were not extraordinary events, but members of a bigger family of explosions. Since GW170817 looked so different from anything we had ever seen before we did not know whether it was an exotic explosion or a common one. Having another event resembling its properties makes us more confident that GW170817 was not a rare finding, and we will probably catch more members of the same family in the near future.

A supernova can be up to 100-times brighter than a kilonova



Gravitational waves are a consequence of energy being released by the merger of two enormous cosmic objects

even if LIGO was working and staring at that patch of sky at the right time, there is no certainty it would have detected anything due to the colossal distance between Earth and GRB150101B, which is over 1,000-times further away than GW170817! However, the researchers are still extremely confident that gravitational waves were still created, even if they weren't able to detect them.

"All neutron star mergers produce gravitational waves; this is something the astronomical community is extremely confident about. The reason for this confidence is that, when it comes to predictions of gravitational waves, mergers of neutron stars and of black holes are extremely straightforward exercises in general relativity," says Van Eerten. "What matters for us is whether these mergers occur sufficiently close enough to detect with gravitational-wave detectors."

Whether these events are frequent or not is something that still needs to be determined. The evolution of telescopes and detectors has helped a lot with this research. Hopefully with the fine array of ground- and space-based telescopes available to modern astronomers the detections of such events could become more frequent. When asking Ryan what this discovery means for our understanding of science and the universe, he replies: "Short-term, identifying the shared properties will help us detect similar events in the future. Long-term, with more observations we can build up a cohesive picture of these events and better understand the physics that drives them."

Both of these goals centre heavily on gathering as much data as possible. Now that astronomers know what they have to look out for it's a matter of keeping a keen eye out for similar events and building a database of neutron star mergers throughout the universe. With a more comprehensive archive astronomers can improve on finding the visible counterpart to gravitational-wave signals. If another enormous event was on the verge of transpiring astronomers would be well-equipped to understand the true intricacies of the merger. This includes understanding how the cosmos' most exotic elements, which make up everyday life on Earth, are made.

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STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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What's in the sky?

4 JAN
The Quadrantids reach their peak of 80 meteors per hour

4 JAN
Conjunction between the Moon and Mercury in Sagittarius

5 JAN
Venus reaches dichotomy (half phase) in the dawn sky, shining at magnitude -4.4

© G Furtado

12 JAN
The Moon and Mars make a close approach within 4°58' of each other in Cetus and Pisces

14 JAN
Open cluster Messier 47 is well placed for observation in Puppis at magnitude 4.4

19 JAN
Open cluster NGC 2516 is well placed for observation in Carina at magnitude 3.8

21 JAN
Total lunar eclipse visible from Africa, Oceania, the Americas, Europe and Turkey

21 JAN
The Moon and open star cluster Messier 44 pass within 0°16' of each other in Cancer

30 JAN
Conjunction between the Moon and Jupiter, passing within 2°45' of each other in Ophiuchus

31 JAN
The Moon and Jupiter make a close approach, passing within 2°45' of each other in Ophiuchus

31 JAN
The Moon and Venus make a close approach, passing within 0°05' of each other in Ophiuchus

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

6 JAN
Partial solar eclipse visible between Eastern Asia and the western United States

6 JAN
Venus reaches greatest elongation west in the dawn sky, shining at magnitude -4.4

12 JAN
Conjunction between the Moon and Mars in Cetus and Pisces

15 JAN
Spiral galaxy NGC 2403 is well placed for observation in Camelopardalis

17 JAN
Open cluster NGC 2451 is well placed for observation Puppis at magnitude 2.8

18 JAN
Comet C/2017 M4 will make its closest approach to the Sun

22 JAN
Conjunction between Venus and Jupiter in Ophiuchus

22 JAN
Venus and Jupiter pass within 2°24' of each other in Ophiuchus

23 JAN
Open star cluster NGC 2547 is well placed for observation in Vela at magnitude 4.7

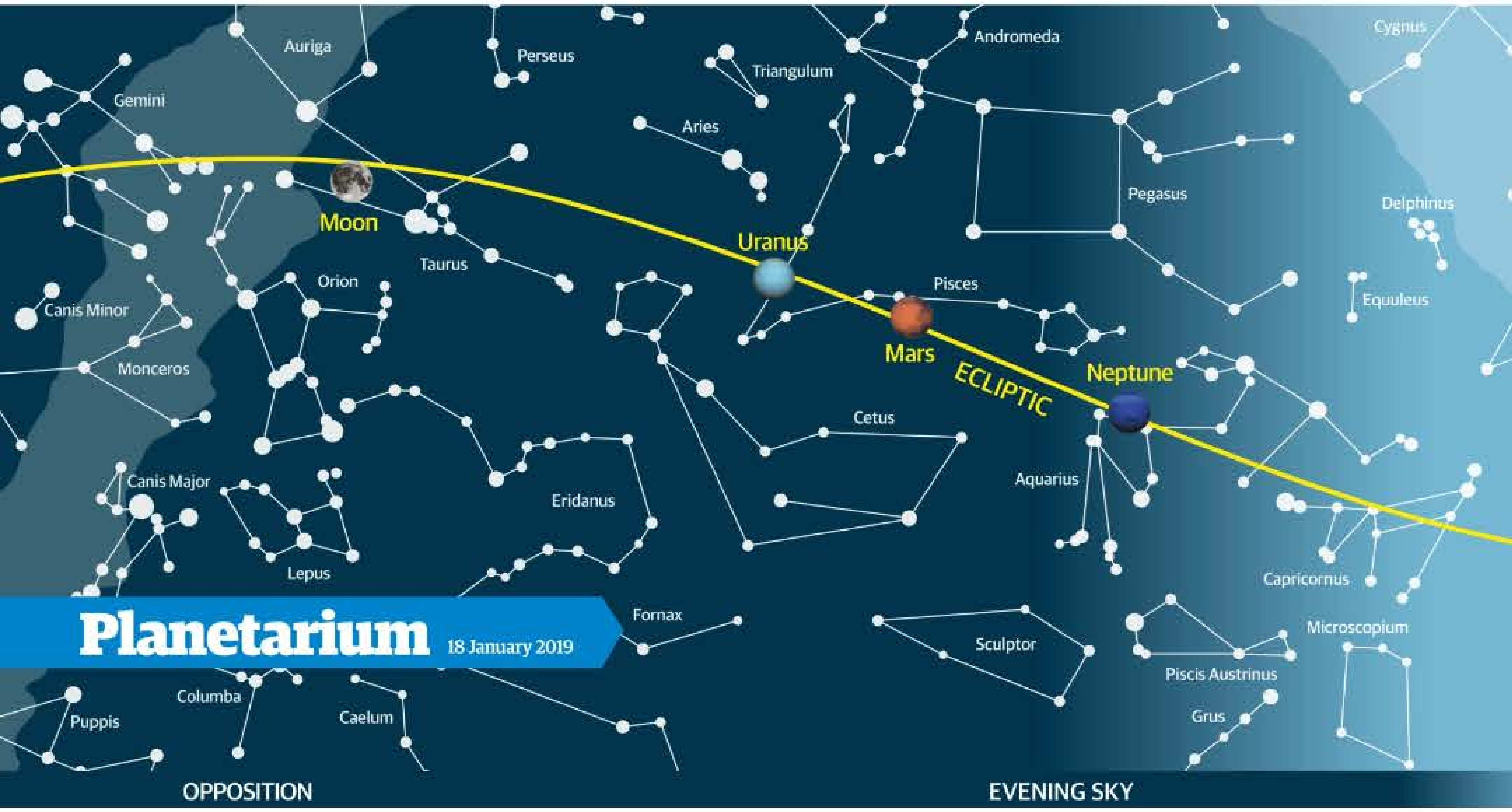
31 JAN
The Beehive cluster (M44) is well placed for observation in Cancer, shining at magnitude 3.1

31 JAN
Open star cluster IC 2391 is well placed for observation, glowing at magnitude 2.5

- Naked eye
- Binoculars
- Small telescope
- Medium telesc
- Large telescope

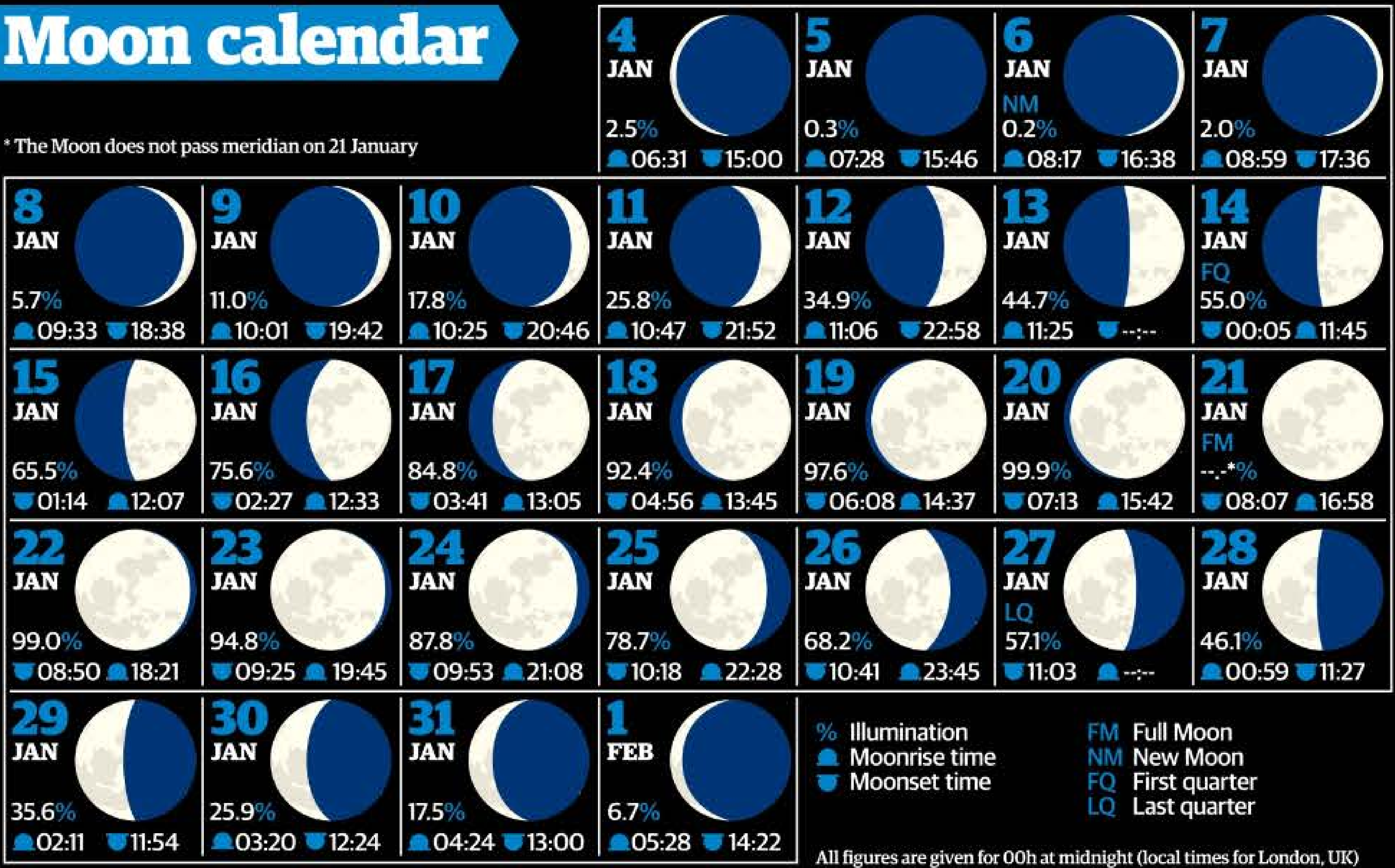
Planetarium

18 January 2019



Moon calendar

* The Moon does not pass meridian on 21 January

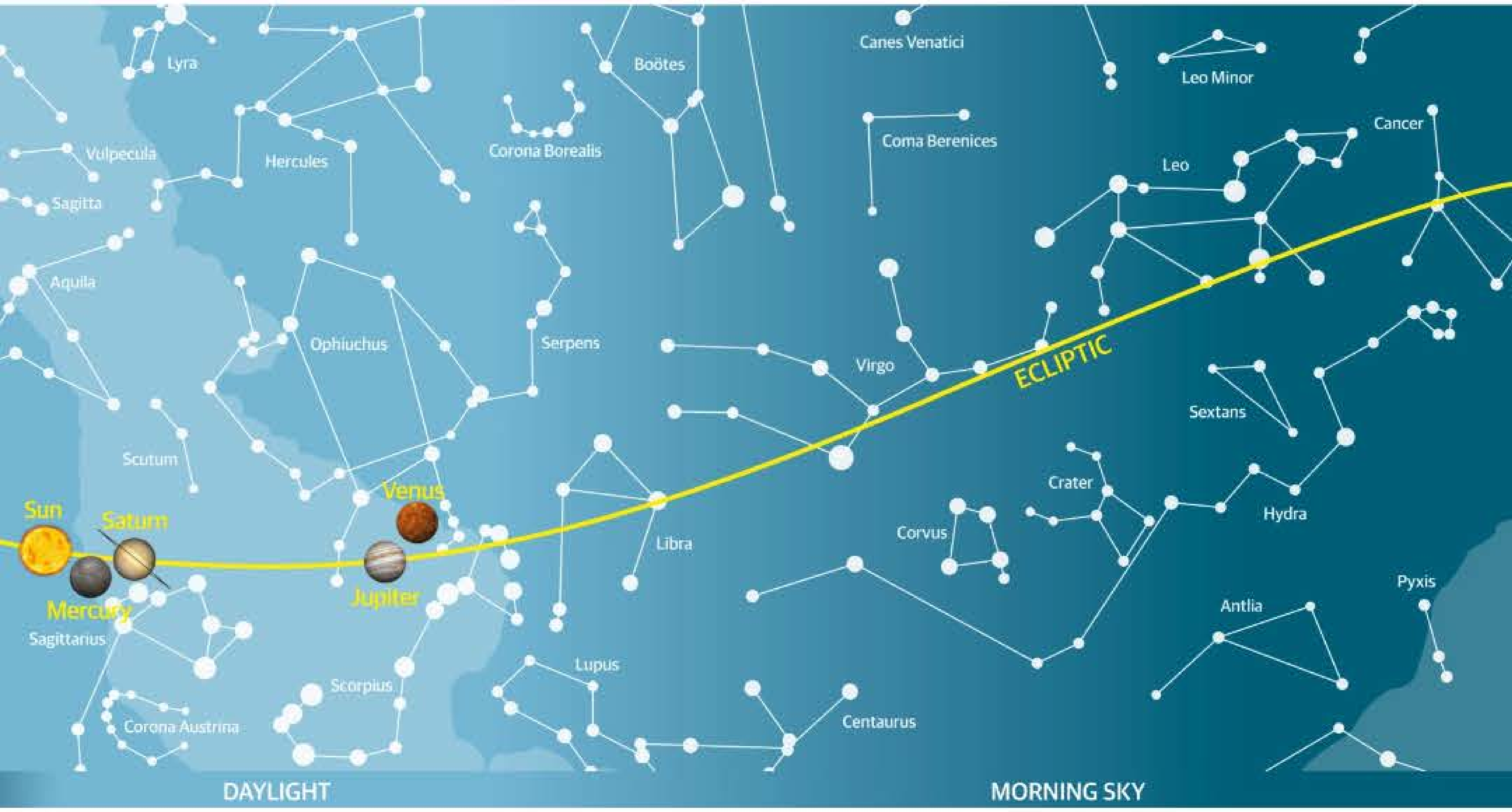


		%	Moonrise	Moonset
4 JAN		2.5%	06:31	15:00
5 JAN		0.3%	07:28	15:46
6 JAN	NM	0.2%	08:17	16:38
7 JAN		2.0%	08:59	17:36
8 JAN		5.7%	09:33	18:38
9 JAN		11.0%	10:01	19:42
10 JAN		17.8%	10:25	20:46
11 JAN		25.8%	10:47	21:52
12 JAN		34.9%	11:06	22:58
13 JAN		44.7%	11:25	--:--
14 JAN	FQ	55.0%	11:45	00:05
15 JAN		65.5%	12:07	01:14
16 JAN		75.6%	12:33	02:27
17 JAN		84.8%	13:05	03:41
18 JAN		92.4%	13:45	04:56
19 JAN		97.6%	14:37	06:08
20 JAN		99.9%	15:42	07:13
21 JAN	FM	--.-*%	16:58	08:07
22 JAN		99.0%	18:21	08:50
23 JAN		94.8%	19:45	09:25
24 JAN		87.8%	21:08	09:53
25 JAN		78.7%	22:28	10:18
26 JAN		68.2%	23:45	10:41
27 JAN	LQ	57.1%	--:--	11:03
28 JAN		46.1%	00:59	11:27
29 JAN		35.6%	02:11	11:54
30 JAN		25.9%	03:20	12:24
31 JAN		17.5%	04:24	13:00
1 FEB		6.7%	05:28	14:22

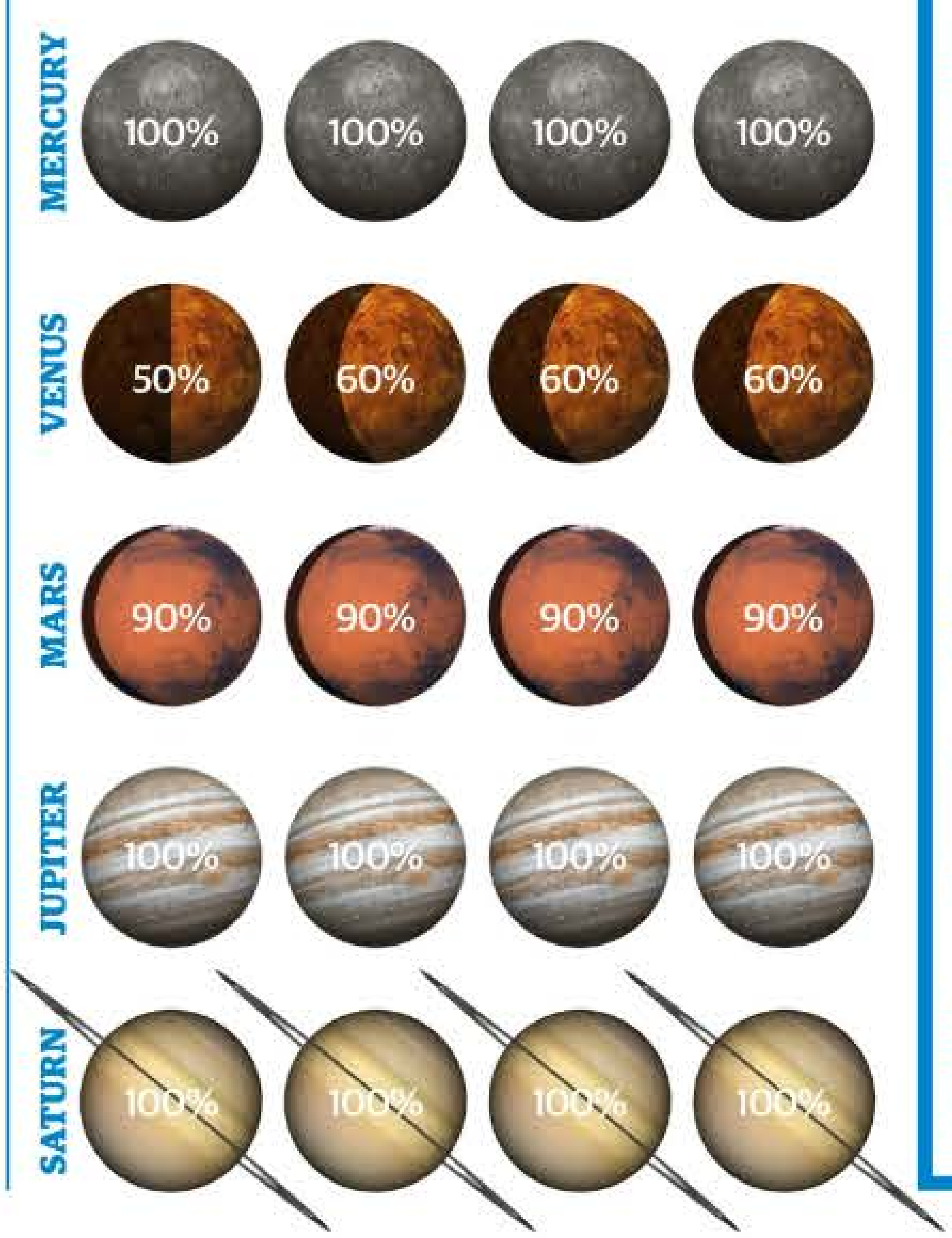
- % Illumination
- Moonrise time
- Moonset time

- FM Full Moon
- NM New Moon
- FQ First quarter
- LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



	11 DEC	18 DEC	25 DEC	31 JAN
MERCURY	100%	100%	100%	100%
VENUS	50%	60%	60%	60%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

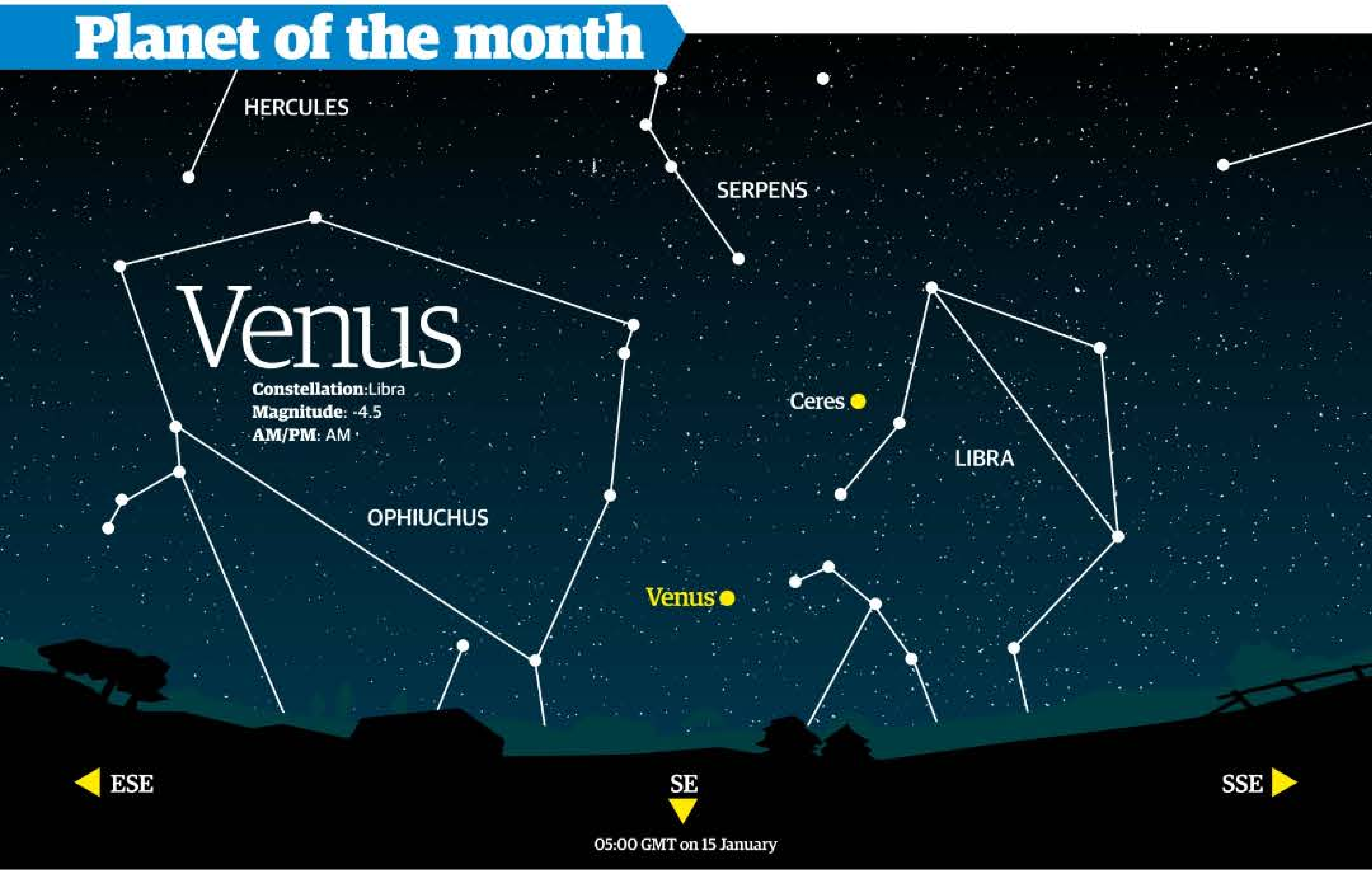
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	04 Jan	17h 51m 23s	-23° 40' 02"	Sagittarius	-0.4	07:27	14:44
	11 Jan	18h 37m 52s	-24° 09' 55"	Sagittarius	-0.6	07:50	14:58
	18 Jan	19h 25m 53s	-23° 35' 45"	Sagittarius	-0.8	08:06	15:23
	25 Jan	20h 14m 46s	-21° 52' 06"	Capricornus	-1.2	08:13	15:58
	31 Jan	20h 56m 56s	-19° 25' 19"	Capricornus	1.5	08:14	16:34
VENUS	04 Jan	15h 38m 57s	-15° 56' 52"	Libra	-4.5	04:21	13:26
	11 Jan	16h 03m 56s	-17° 30' 53"	Scorpius	-4.4	04:32	08:55
	18 Jan	16h 39m 03s	-18° 54' 21"	Ophiuchus	-4.3	04:45	08:58
	25 Jan	17h 11m 16s	-20° 01' 48"	Ophiuchus	-4.3	04:57	13:08
	31 Jan	17h 39m 48s	-20° 43' 21"	Ophiuchus	-4.3	05:07	13:08
MARS	04 Jan	00h 06m 35s	+00° 27' 44"	Pisces	0.5	11:13	23:26
	11 Jan	00h 23m 42s	+02° 28' 19"	Pisces	0.6	10:52	23:26
	18 Jan	00h 40m 56s	+04° 27' 42"	Pisces	0.7	10:30	23:27
	25 Jan	00h 58m 17s	+06° 25' 03"	Pisces	0.8	10:09	23:28
	31 Jan	01h 13m 17s	+08° 03' 30"	Pisces	0.9	09:51	23:38
JUPITER	04 Jan	16h 42m 57s	-21° 37' 26"	Ophiuchus	-1.8	06:03	13:51
	11 Jan	16h 49m 03s	-21° 49' 25"	Ophiuchus	-1.8	05:43	13:28
	18 Jan	16h 54m 57s	-21° 58' 08"	Ophiuchus	-1.8	05:23	13:05
	25 Jan	17h 00m 36s	-22° 06' 38"	Ophiuchus	-1.9	05:02	12:42
	31 Jan	17h 05m 13s	-22° 12' 59"	Ophiuchus	-1.9	04:43	12:23
SATURN	04 Jan	18h 49m 44s	-22° 27' 47"	Sagittarius	0.5	08:16	15:51
	11 Jan	18h 53m 17s	-22° 23' 52"	Sagittarius	0.5	07:51	15:28
	18 Jan	18h 56m 48s	-22° 19' 40"	Sagittarius	0.5	07:27	15:04
	25 Jan	19h 00m 15s	-22° 15' 14"	Sagittarius	0.5	07:02	14:41
	31 Jan	19h 03m 09s	-22° 11' 17"	Sagittarius	0.6	06:41	14:20

This month's planets

Venus makes a spectacular appearance in the dawn sky, but there will be opportunities to observe other members of the Solar System

Planet of the month



Venus

Constellation: Libra
Magnitude: -4.5
AM/PM: AM

05:00 GMT on 15 January

The world often referred to as 'Earth's Twin' is by far the brightest thing in the sky this month apart from the Sun and Moon, and again is a Morning Star, visible to the naked eye as a flaring silvery blue-white spark high in the southeast from the early hours right through until sunrise.

Venus is a fascinating world, but one that many planetary scientists - and amateur astronomers - feel has been rather overlooked considering its proximity to Earth and its prominence in our sky. Why? Perhaps it's because its surface is hidden from our view, smothered beneath that curdled, thick carbon dioxide atmosphere, so seeing anything on it takes more effort. Perhaps it's because it's not seen as a world where life could exist, so it's seen as less interesting and less important? It's a shame because, as any Venus fan will tell you, Venus is a world with geology, landscapes and surface features just as worthy of study as the rocky plains and deep valleys of Mars, the molten sulphur-vomiting volcanoes of Io or the sweeping icy plains of Enceladus.

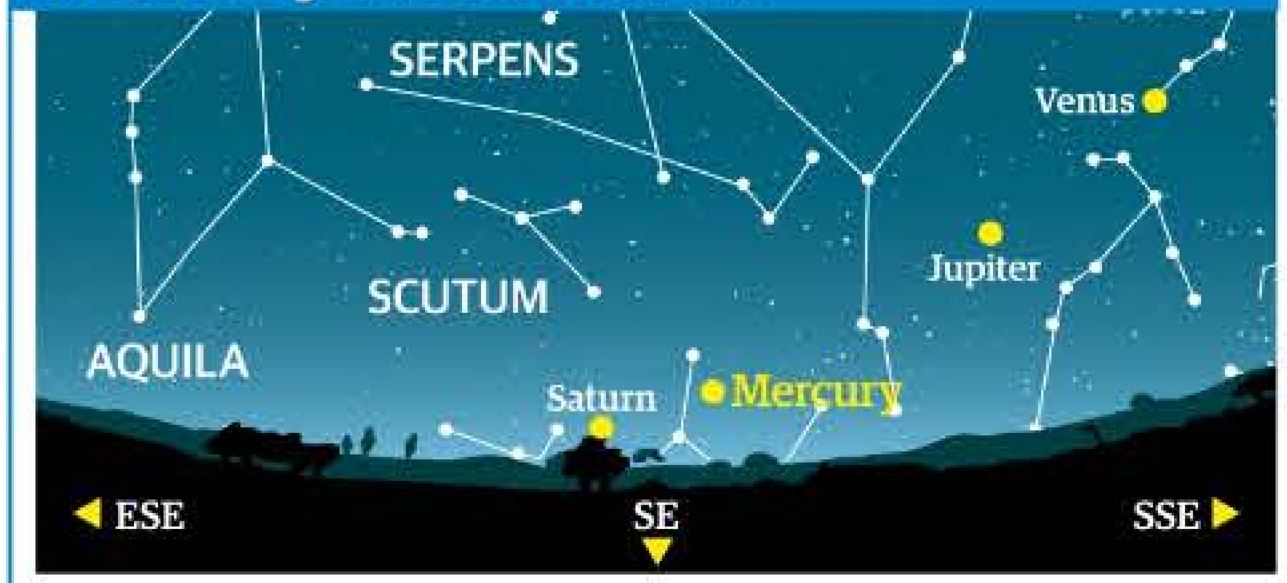
At the start of the month Venus will be rising four hours before the Sun, so you'll be able to see it blazing in a properly dark sky. Even if you have no knowledge of the stars and constellations and don't know which direction is southeast it won't matter; you'll be able to spot Venus because as soon as you start to look around the sky it will draw your eye.

As the days pass Venus will start to move back towards the Sun but will remain easily visible to the naked eye through the month - it will still be rising two-and-a-half hours before the Sun at month's end.

During January this beautiful Morning Star will not be short of company either. If you're in a fit-enough state to be out looking at the sky in the early hours of New Year's Day you'll be able to see a lovely crescent Moon shining to the upper right of Venus. The following morning the Moon, now an even slimmer crescent, will be to the lower left. On 22 January Venus will have a close encounter with Saturn, when the two worlds will be less than two-and-a-half degrees apart, making a beautiful pair.

But you really need to cross your fingers for a clear sky on the morning of 31 January, when Venus will be part of what should be a stunning gathering of worlds in the southeast before sunrise. You'll see Venus blazing with the crescent Moon on its right and bright Jupiter on the other side of the Moon. You'll have the best view of this if you can observe it from somewhere with a dark sky unspoiled by light pollution and a low southeastern horizon.

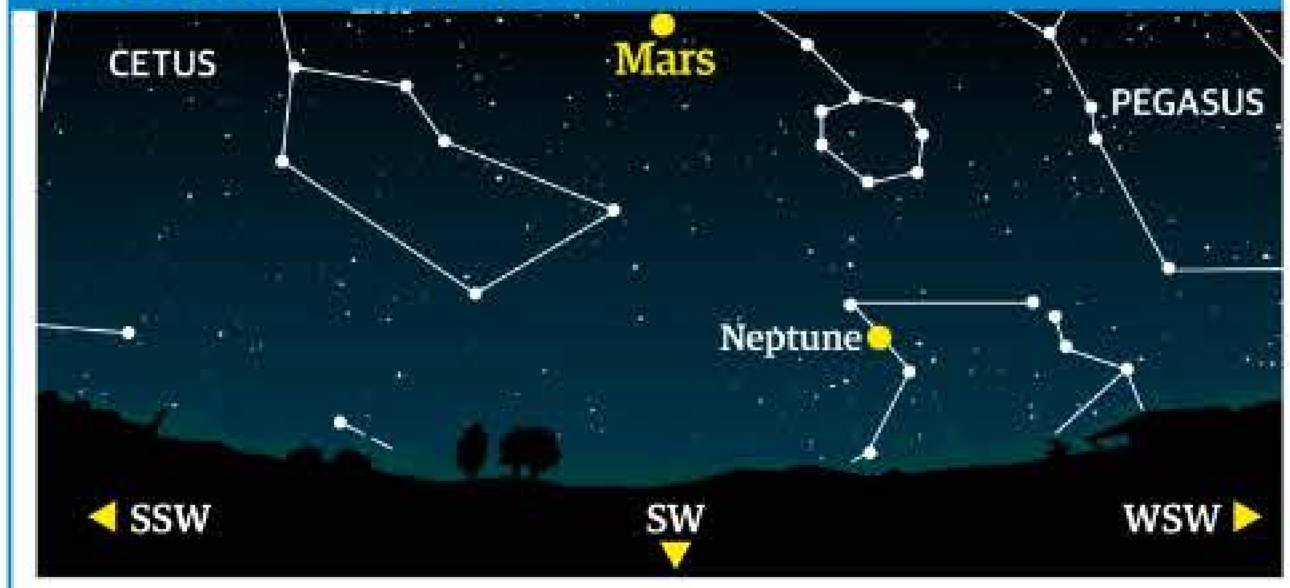
Mercury 08:00 GMT on 07 January



Constellation: Ophiuchus
Magnitude: 0.4
AM/PM: AM

At the start of the month Mercury will be very low in the southeast to the lower left of brighter Jupiter, which itself will be to the lower left of brilliant Venus. At magnitude 0.4 the elusive little world will struggle to shine through the bright sky, and you might need binoculars to pick it out – but only before the Sun rises.

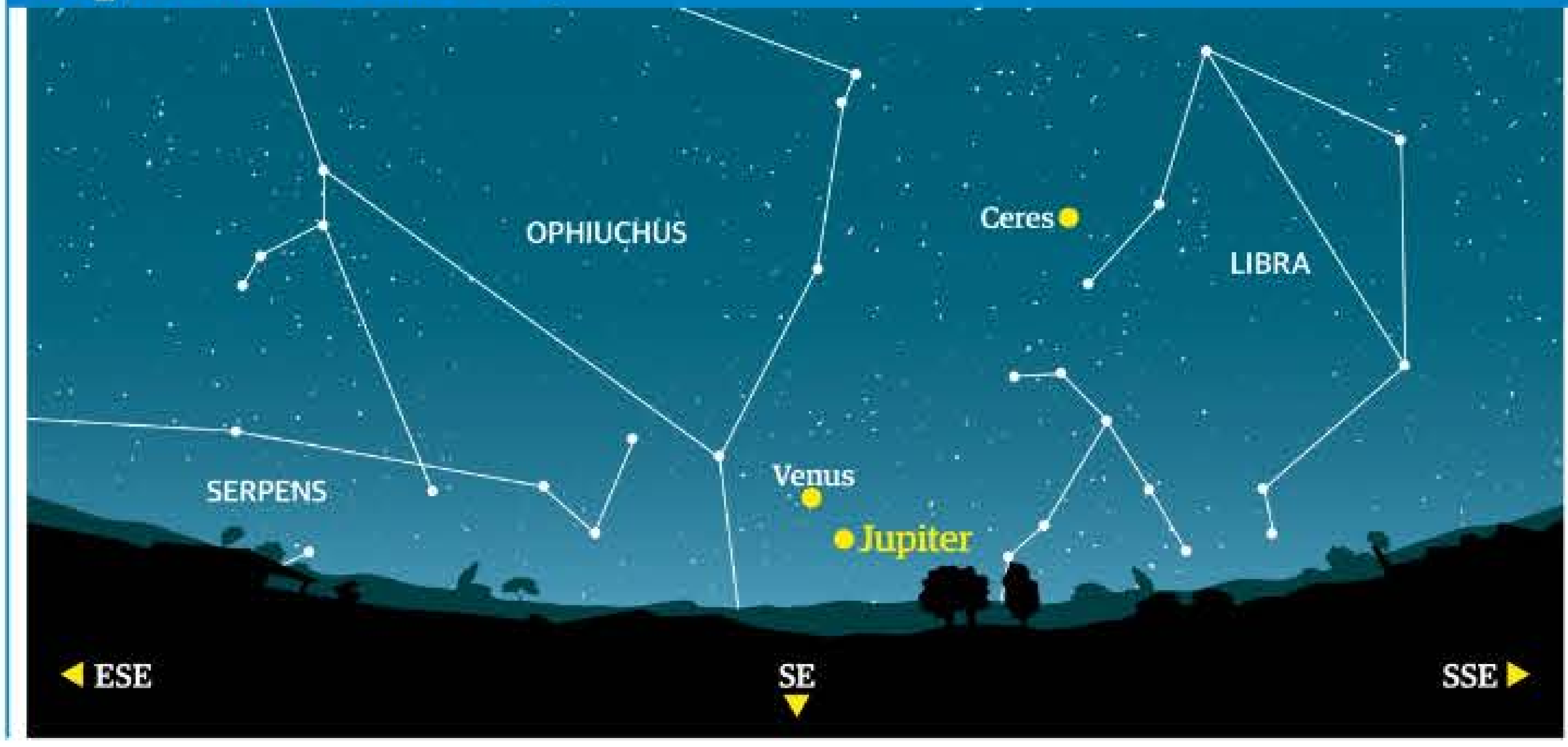
Mars 20:00 GMT on 13 January



Constellation: Pisces
Magnitude: 0.5
AM/PM: PM

You'll find Mars high in the southeast after sunset. Through a telescope Mars' disc will be small, but you should still be able to see the white button of its south polar cap at high magnification. Look for a young crescent Moon shining close to Mars low in the southwest on the evenings of 12 and 13 January.

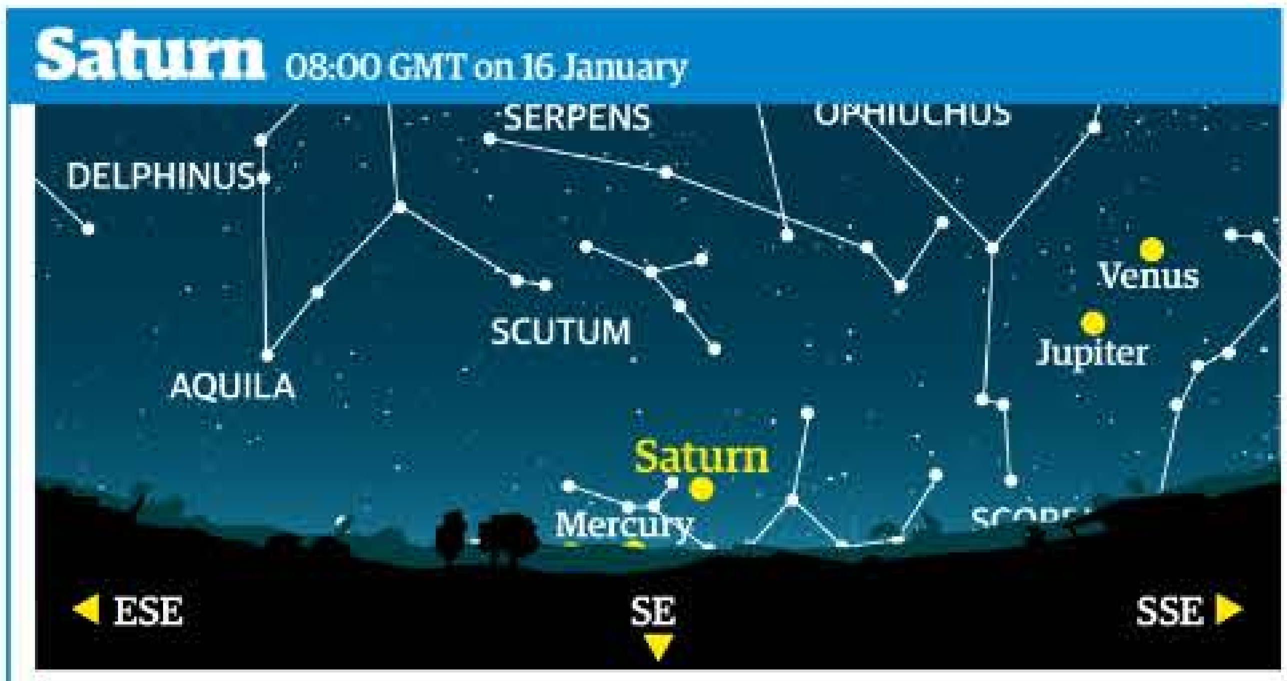
Jupiter 05:20 GMT on 22 January



Constellation: Ophiuchus
Magnitude: -1.8
AM/PM: AM

The largest planet in our Solar System is a strikingly bright morning star, visible in the southeast before sunrise. Shining brightly at magnitude -1.8 it would easily be the brightest object in the morning sky if much brighter Venus wasn't blazing up there to its upper right. Through January Jupiter and Venus will appear to drift towards each other until they pass on 22 January. On that morning they'll be less than two-and-a-half degrees apart and will resemble a lovely double star in the pre-dawn sky. Look out for a very thin waning crescent Moon shining close to Jupiter on the morning of 3 February.

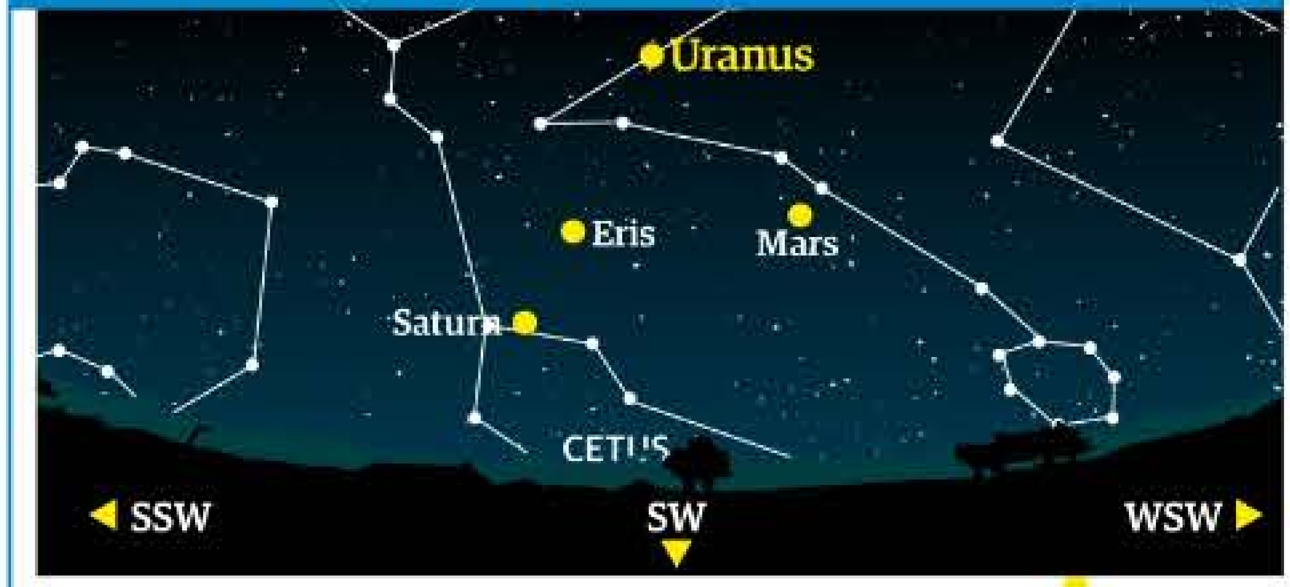
Saturn 08:00 GMT on 16 January



Constellation: Sagittarius
Magnitude: 0.6
AM/PM: AM

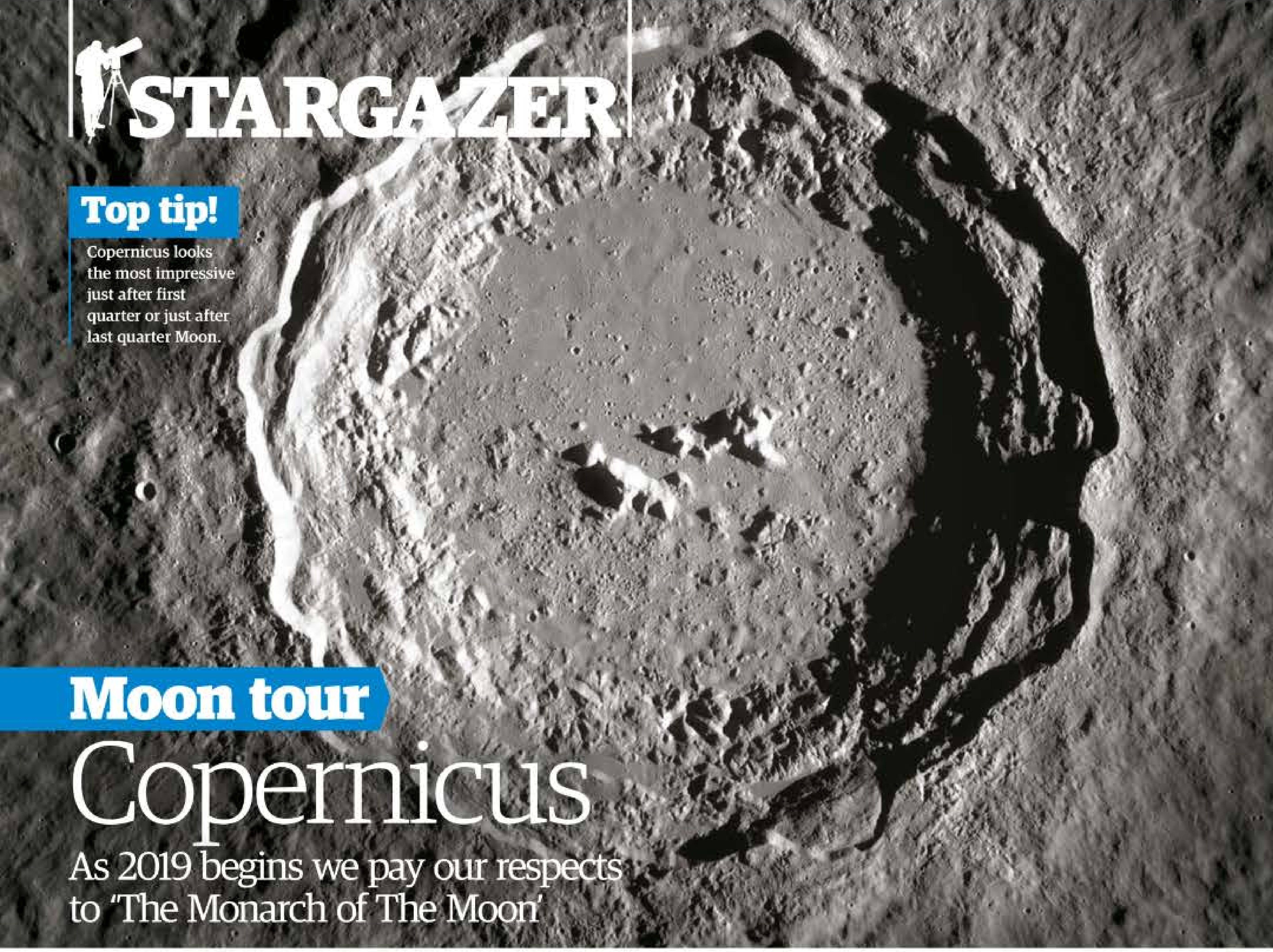
At the start of January Saturn will be just a Moon's width from the Sun, so impossible to see. As days pass the Ringed Planet will slowly drift away from our star, but will remain too close to be seen until the month is almost over, and even then it will be hard to see, very low in the southeast for less than an hour before sunrise.

Uranus 20:00 GMT on 20 January



Constellation: Pisces
Magnitude: 5.8
AM/PM: PM

Shining at magnitude 5.8 Uranus is technically visible unaided, but that brightness is misleading. Uranus is only as bright as the faintest stars the naked eye can see. On clear evenings during January Uranus can be found high in the southwest after sunset, close to the sharp tip of the 'V' of Pisces.



Top tip!

Copernicus looks the most impressive just after first quarter or just after last quarter Moon.

Moon tour

Copernicus

As 2019 begins we pay our respects to 'The Monarch of The Moon'

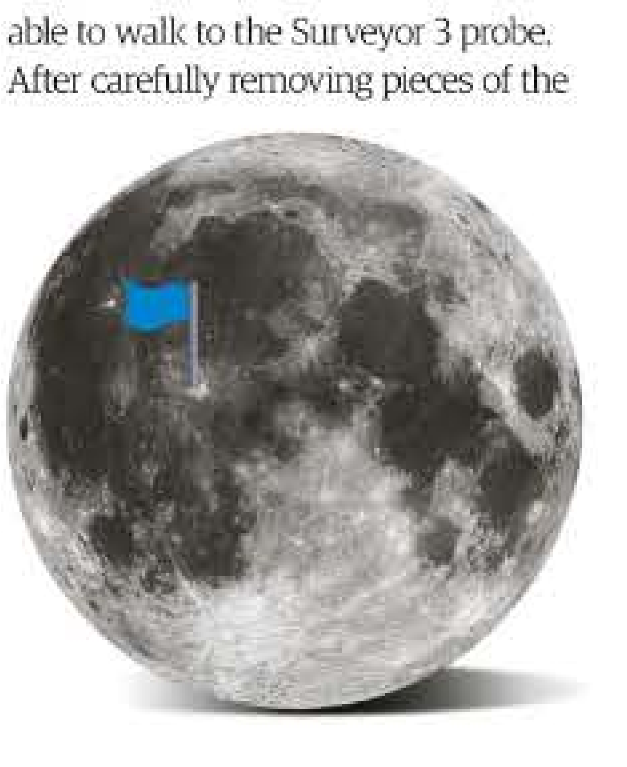
If you've ever seen a TV documentary about the Moon you'll have seen a space boffin enthusiastically hurling a stone into a tray full of flour to demonstrate how impact craters are formed. Of all the hundreds of thousands of craters on the Moon, one looks exactly like the feature these dramatic demonstrations produces - a deep, sharp-edged pit, like a skull's eye socket, surrounded by rays of debris.

Copernicus looks exactly like a lunar crater should: a great hole in the Moon with a dark, shadowed floor; a high, sky-scratching rim and lots of bright rays of dust and pulverised rock splashing away from it. Its nickname, The Monarch of the Moon, is entirely justified - no other crater comes close to it for sheer 'wow' factor when seen through a telescope eyepiece. That's why Moon observers go back to it again and again and again, staring down into it every chance they get.

Copernicus is young in lunar terms. It was formed between 800 million and 1 billion years ago when the most advanced forms of life on Earth were essentially clumps of scum floating about in the oceans. One day the Moon was struck by a large asteroid, and the enormous explosion caused by the impact blasted a huge hole out of the area of the Moon we now know as Oceanus Procellarum, or the Ocean of Storms. The gaping pit left behind was almost four kilometres (2.5 miles) deep and more than 93 kilometres (58 miles) wide. But the impact didn't just blast out a hole; it sent enormous amounts of debris spraying out across the lunar landscape. Some of it fell back down to the Moon, leaving bright rays of ejecta on the landscape. The longest of these debris rays stretches for over 800 kilometres (50 miles) and can even be seen with the naked eye when the Moon is full, looking like white chalk lines drawn on the Moon's darker face.

Seen through a telescope, or from an orbiting probe, Copernicus is roughly hexagonal in shape. Its walls are steep and terraced on all sides, giving the strong impression of a flight of stairs descending to its floor. High magnification shows where a wide shelf of rock has dropped down on the western side and also hints at landslides in several places. The northern part of the crater's floor is quite flat, but the southern half is hummocky and hilly, pocked here and there with many smaller, much younger craterlets. In the centre of the crater a trio of mountains protrude from the lava plain, the tallest one, close to the western wall, has a peak which rises above the crater's floor.

In November 1969 the Apollo 12 Lunar Module Intrepid set down on a landing site around 350 kilometres (217 miles) south of the huge crater. So precise was Intrepid's landing that its crew, Pete Conrad and Alan Bean, were able to walk to the Surveyor 3 probe. After carefully removing pieces of the probe to be studied back on Earth, they collected samples of rock, some of which might have showered from the sky after the formation of Copernicus almost a billion years earlier.



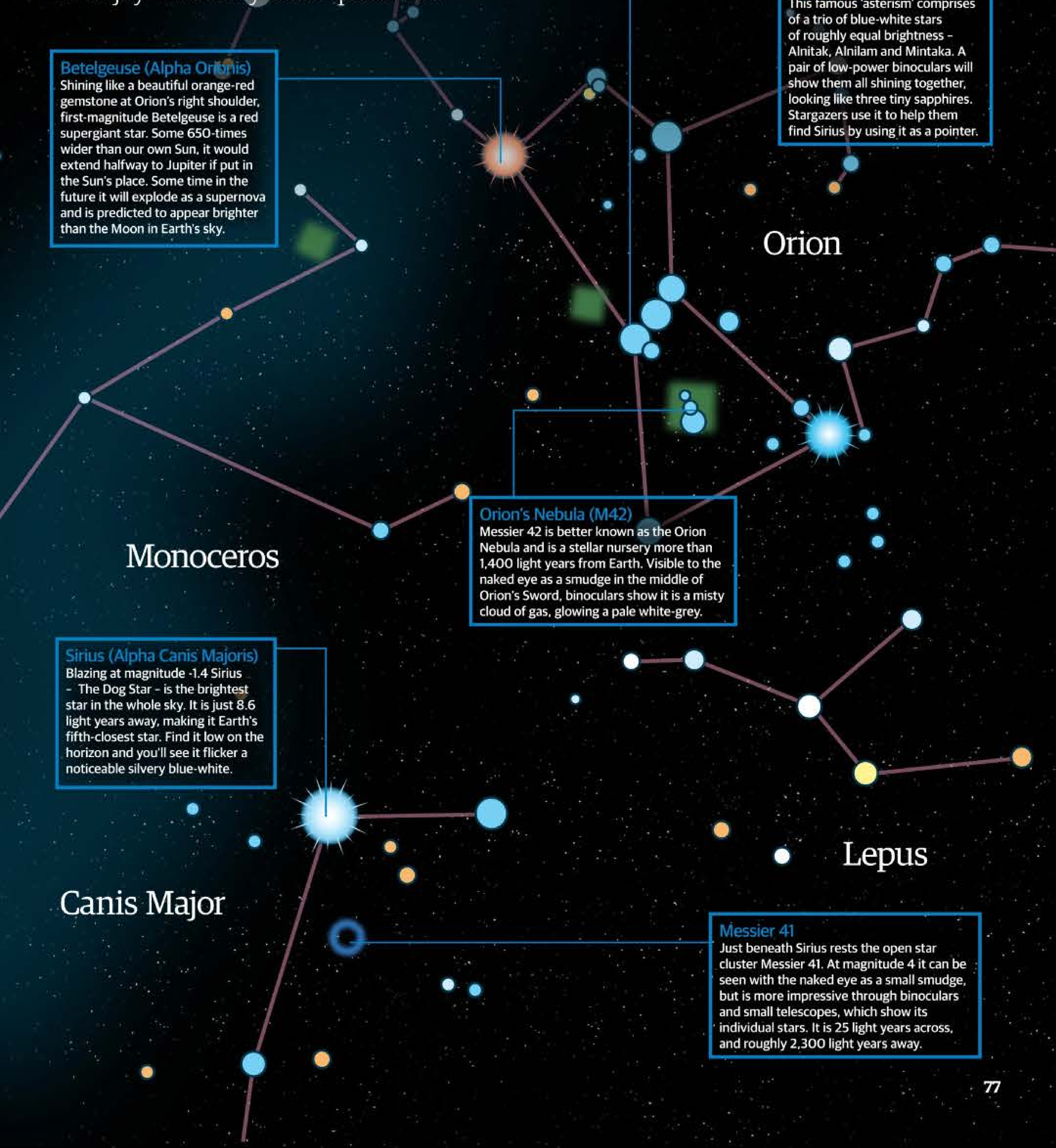
So, how and when can you see this celebrity crater during this month?

At the start of our observing period Copernicus is hidden from view, deep in lunar night. You'll have to wait until the evening of 14 January for your first sighting of it as it emerges from the darkness with the approach of the terminator, the line between night and day. As lunar dawn breaks over Copernicus' eastern horizon it will come fully into view the next evening, the 15th, and from then until the 28th will be available for your attention with binoculars or a telescope. When the Moon is full on 21 January the crater's system of rays will appear at their most dramatic and obvious. By the 29th Copernicus will be hard to see as the terminator sweeps towards it, and it will vanish from our view on the 30th, swallowed up by the bitter lunar night once more when the Moon will be a waning crescent glowing in the east before dawn.

© NASA

This month's naked eye targets

The New Year brings some familiar sights to enjoy with very little optical aid



Betelgeuse (Alpha Orionis)
Shining like a beautiful orange-red gemstone at Orion's right shoulder, first-magnitude Betelgeuse is a red supergiant star. Some 650-times wider than our own Sun, it would extend halfway to Jupiter if put in the Sun's place. Some time in the future it will explode as a supernova and is predicted to appear brighter than the Moon in Earth's sky.

Orion's Belt
This famous 'asterism' comprises of a trio of blue-white stars of roughly equal brightness – Alnitak, Alnilam and Mintaka. A pair of low-power binoculars will show them all shining together, looking like three tiny sapphires. Stargazers use it to help them find Sirius by using it as a pointer.

Orion's Nebula (M42)
Messier 42 is better known as the Orion Nebula and is a stellar nursery more than 1,400 light years from Earth. Visible to the naked eye as a smudge in the middle of Orion's Sword, binoculars show it is a misty cloud of gas, glowing a pale white-grey.

Sirius (Alpha Canis Majoris)
Blazing at magnitude -1.4 Sirius – The Dog Star – is the brightest star in the whole sky. It is just 8.6 light years away, making it Earth's fifth-closest star. Find it low on the horizon and you'll see it flicker a noticeable silvery blue-white.

Messier 41
Just beneath Sirius rests the open star cluster Messier 41. At magnitude 4 it can be seen with the naked eye as a small smudge, but is more impressive through binoculars and small telescopes, which show its individual stars. It is 25 light years across, and roughly 2,300 light years away.

HOW TO START YOUR OWN ASTRONOMICAL SOCIETY

What do you do if you want to join a club or society but there isn't one nearby? Simple: start one yourself

Written by Stuart Atkinson

For many, one of the greatest joys of amateur astronomy is that it is a hobby that can be done on your own. In fact, it's probably the perfect hobby for people who don't mind their own company. You don't *need* to be with other people to enjoy the beauty of a clear, starry night, or the sight of a comet glowing in the sky, or meteors skipping across the heavens during a shower. Standing on their own in a field, a country lay-by or on a hilltop, looking up at the stars, is many people's idea of heaven.

However, for some people being an amateur astronomer can be a lonely and isolating experience, and after a while of going solo they find they really do want to do it with others. Luckily, today there is a lot of online support for the lone observer: there are thousands of astronomy-related Facebook groups and Twitter accounts stargazers can join if they want to ask for advice and share their experiences without even going near another real person if they don't want to.

Online communities can be really friendly and supportive, but for some people there's just no substitute for being part of a physical group that meets, talks and shares their passion. The next step is to join their local astronomical society – they can meet people with the same interests, learn from them and share the wonders of the night sky with them as part of a group – and today every city and most large towns have at least one astronomical society which meets regularly and holds lectures and observing events for its members.

But what if there isn't one near you? What do you do then? With a bit of work, you can start up an astronomy society yourself!

Read on for our guide on how to start a brand new, successful astronomical society and help it to grow into a group that will give pleasure to you and many other budding and seasoned astronomers too.

© Sumwat Punnarhon / EyeEm

1 HOW TO FIND MEMBERS FOR YOUR SOCIETY

A society will give you the chance to try each others' kit

USE SOCIAL MEDIA

These days social media is a great way of spreading the word about a new business, and the same is true for launching a new astronomy society too. Every town and city will have one or more Facebook pages and Twitter accounts associated with it, so post messages on them letting people know what you're trying to do and invite them to get in touch with you if they're interested in joining. But don't drown them in information - keep it simple: "Are you interested in the night sky? Would you be interested in starting an astronomical society? Me too! I'd love to hear from you..."

GET HELP FROM YOUR LOCAL NEWSPAPER & RADIO STATIONS

> "Post messages letting people know what you're trying to do"

A great way of recruiting members for your new society is by getting your local newspaper(s) and radio stations involved. Local reporters are always looking for community-based stories, and they will love to hear from you. Look for editorial contact details on their website and email them with details of your search for members. The worst they can do is tell you they can't help, but they might well write or broadcast a piece about your fledgeling society which will help you attract members.

GO BACK TO BASICS

It's important to remember that - despite what banks and marketing companies would have us believe - not everyone is online. Many people, for various reasons, remain unconnected to the internet, and the 'joys' of the World Wide Web are a mystery to them. So you will need to go back in time to how people used to publicise events before the world went digital - and put up advertising posters! An A4 sheet - or even just a small card - in shop windows, or in supermarkets, with your plans and your contact details on will attract people who don't use social media.

2 FINDING A MEETING VENUE

REQUIREMENTS FOR A VENUE

When you are sure there is enough interest in forming a society you will need to find somewhere for it to hold its meetings - you can't just hang out in a bus shelter. But don't just take the first free room you can find. Your meeting venue will need to have the following: at least some parking for your members, its own chairs and tables, heating for winter meetings, disabled access and toilets and plenty of power sockets for equipment. Those basic requirements will rule out many possible meeting venues.

MONEY, MONEY, MONEY

It is *very* important to find out in advance the financial obligations and arrangements you are entering into before hiring a room for your meetings. When making your enquiries ask how much the room will cost per meeting, when the money is to be paid and how the fee is to be paid. Unless your room is free you will need to set up a bank account for your society, which means having a treasurer to collect membership fees and pay the room-hire costs. We'll come back to that.

IDENTIFYING POSSIBLE VENUES

When looking for a venue for your society meetings consider approaching the following:

- Local schools may have classrooms available for use after school hours.
- Your local library might have a meeting room for hire.
- Your local college might have a suitable room available.
- Your local community centre.
- Parish halls are often used by astronomy societies.

3 YOUR FIRST MEETING!

KEEP IT SIMPLE

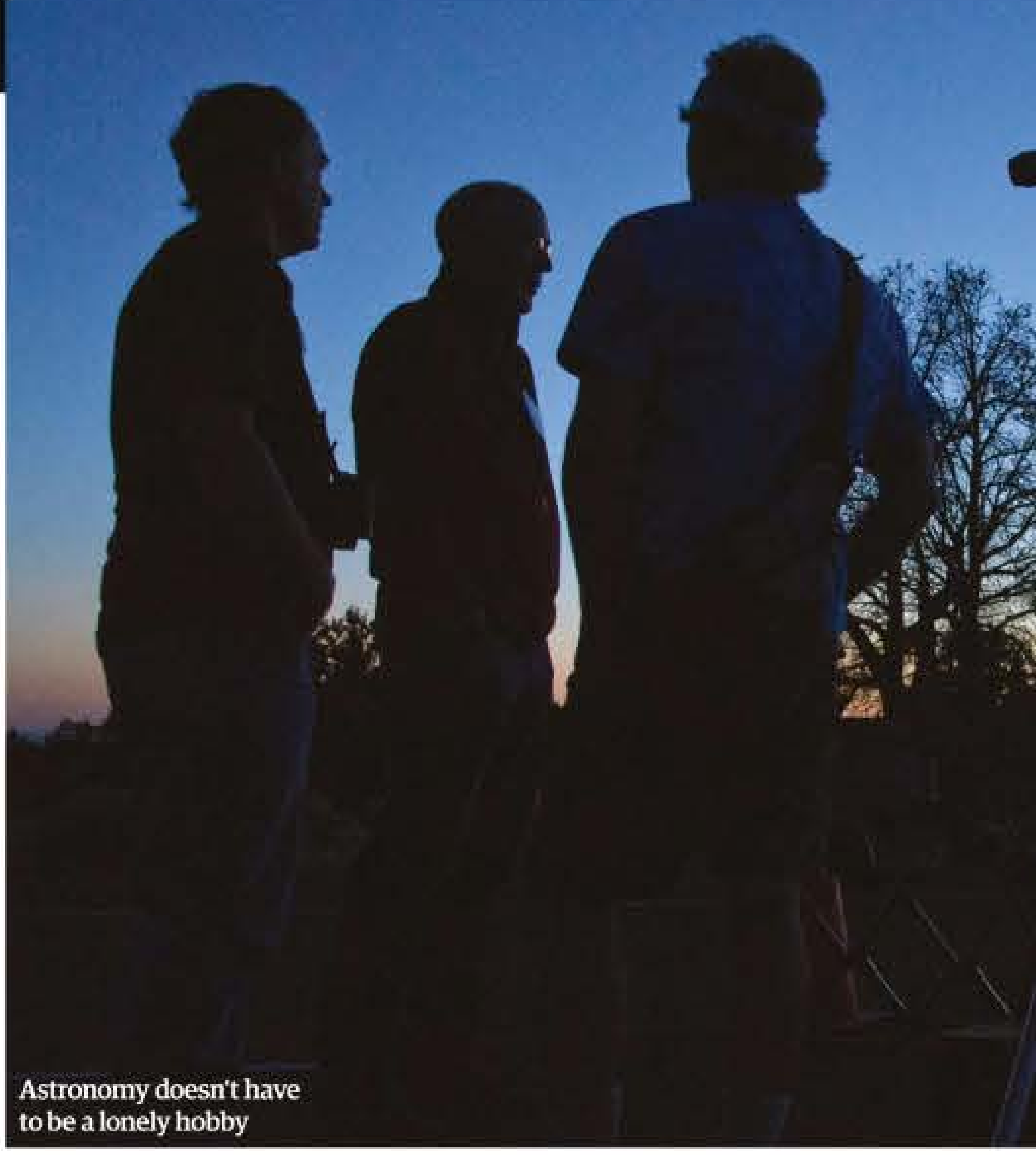
You did it! You're holding your first meeting! You have members! Great - but don't try to do too much. All you need to do on your first night is thank everyone for coming, make sure everyone there feels welcome and then have a general chat about what you're hoping to do and what people want to get out of the group. Keep it friendly and lighthearted, and take lots of notes so you can look back on them later; it will be so busy you'll forget half of what happened when you get back home!

DISCUSS ROLES WITHIN THE SOCIETY

The best astronomy societies are informal, friendly and not tied up in red tape. However, for things to run smoothly it is essential that certain 'jobs' are taken care of, and that means you will need to have a core team of people with responsibilities for certain things - a committee, if you like. At your first meeting discuss the need for having at least a treasurer to handle the society's financial affairs and someone to set-up and manage the society's online presence - you'll need a website or at least a Facebook page. By the way, your society will already have a secretary who will be responsible for organising meetings and co-ordinating society activities - you! It was your idea in the first place, so you elected yourself secretary. Congratulations!

DISCUSS & SOURCE EQUIPMENT

Astronomy is a very visual subject. Amazing new images of the planets are taken by space probes every week, and beautiful photos of galaxies, clusters and nebulae are taken by telescopes all the time. Your members will enjoy seeing and discussing them - especially those without internet access - so you will need to be able to show these images at your meetings. That means you will need access to a laptop, a projector that works with a laptop and a screen. If your meeting venue doesn't already have these for you to use - schools, libraries and museums probably will - you'll need to provide your own. At the first meeting find out if any of your members have them or can source them. If not, that will be your responsibility.



Astronomy doesn't have to be a lonely hobby

DISCUSS MEMBERSHIP FEES

It is very important at your first meeting to discuss membership fees. Unless your meeting venue is free you will need to pay for it somehow, and that means asking your members for money - how much money and when and how you collect it from them will need to be agreed. Membership fees must at least cover the cost of your venue hire, and it is a good idea to have extra money in the society bank account to help pay for guest speakers and expenses. So - how much per person? Paid monthly, per meeting, as an attendance fee or paid annually as a single membership fee? Paid in cash, by cheque or direct debit?

> "Unless your meeting venue is free you will need to pay for it somehow, and that means asking members for money"

DISCUSS POTENTIAL SOCIETY OBSERVING SITES

It's great to look at beautiful photos of the stars and planets at your meetings and discuss the latest discoveries and missions, but at some point your members will want to get out there under the stars and look at the real sky, and that means you'll need to have a society observing site. You might have somewhere in mind yourself, somewhere you go to stargaze, but ask people at the meeting where *they* go, because they might know somewhere better. Suggestions will probably include your local park, a school playing field or a lay-by or car park out of town.

PLAN SITE VISITS

After your discussion you will have a few candidate observing sites, so organise a trip out to look at them with a few of your new members - your first society event! This might just involve meeting up at the park or a school playing field or driving out of town together to a darker location. Some sites will be more suitable than others, but one will stand out from the rest. It will have parking for a number of cars, a flat area to set up telescopes and equipment on and as little light pollution as possible. Be aware of safety too: if that site is a popular meeting place for groups of youths after dark your members may not feel - or be - safe there.

A projector is something you will need for your club

WRAPPING UP YOUR FIRST MEETING

Before your first meeting ends and everyone heads home, bite the bullet and ask them how they thought it went - be prepared for criticism, which will help you make your second meeting better. Also make sure you collect contact information from everyone there - their email addresses or postal addresses if they don't have email - and make sure they have yours, too. Tell them you will confirm details of the next meeting - which you will already have discussed at your first meeting - and invite them to send you additional feedback about how they thought the first meeting went.

DON'T TAKE IT TOO SERIOUSLY!

The most important thing to remember during your first meeting is to not take it all too seriously. Keep things friendly and informal and try to make sure no one feels out of place or pressured to join in. Bear in mind that your new members will be a mix of absolute beginners and stargazers with some experience; confident, talkative people and shy, quiet people. You'll feel a little like a circus ringmaster trying to keep them all involved, but hey, this was your idea in the first place!

4 YOUR SECOND MEETING AND MOVING THINGS FORWARD

PLANNING EVENTS AND MEETINGS

At your second meeting you should discuss more seriously what you want the society to do over the coming months. For example, how many meetings should involve guest speakers and what subjects would you like them to talk about? Would members like to go on any trips to local observatories or museums - and, if so, who will organise the date and the transport? How often do your members want meetings to involve actual observing?

FINDING & HOSTING GUEST SPEAKERS

One thing is certain - you will need to book some guest speakers for your society meetings. You can't do everything on your own, and members will expect to hear some interesting lectures and presentations for their membership fees. But how do you find them? If your local university has an astronomy department they might be able to provide a speaker or two. Look at the websites of other astronomy groups in your surrounding area and see who has spoken at their meetings, then email them inviting them to come and speak at yours - but be aware that many speakers will need travel expenses and/or a fee, which you will need to fund through your membership fees or through additional payments.

KNOW YOUR EQUIPMENT

It is very important that you have access to all the equipment needed for your meetings, such as a laptop, projector and screen, but it is just as important that there will always be someone at your meetings who knows how to use them. Also, when arranging visits by guest speakers check if they will want to use their own laptop with your projector or will just bring their talk on a USB stick to use with yours. Check in advance with your speaker that you have the right cables to connect their laptop to your projector - VGA or HDMI? It could be useful to have a VGA-HDMI adaptor to hand.

DON'T LEAVE BEGINNERS BEHIND

As your new society grows it will be easy to get carried away and forget why you started it - and why you got into astronomy - in the first place: your love of the night sky. It's fine to focus some meetings on high-tech equipment, photographic processes and the latest discoveries in astrophysics, and your more advanced members will expect that, but many of your members will just want to know about amazing and beautiful things happening in the sky. Don't leave them behind. Make sure some meetings are targeted at your absolute beginners so they don't feel undervalued.

KEEP YOUR PRESS CONTACTS UPDATED

As your society gets into its stride make sure you keep in touch with any contacts you made on the local newspapers and radio stations who helped you promote your new society back at the start; they'll not only be interested to hear how things are going but will be glad to hear that they played some part in your new society's successful launch. They might even be interested in doing a follow-up piece on your group. Don't just send them details of events and activities your society organises; invite them to them. They might come and report on what happened - publicity you can't buy!

Once established you can set up events, like star parties

© Giuseppe Donatiello

How to...

Capture this month's total lunar eclipse

In the early hours of 21 January the full Moon will grow dark and turn orange as it moves through Earth's shadow - don't miss it!

You'll need:

- ✓ Good observing site
- ✓ Binoculars or small telescope (optional)
- ✓ DSLR camera on tripod (optional)
- ✓ Warm clothing
- ✓ Hot drink and snacks

January can be a very unsettled month when it comes to the weather, but when the sky is clear the temperature plummets, leaving behind an inky-black sky strewn with stars as bright and colourful as jewels. As if that wasn't enough to look forward to, on the morning of 21 January we'll have a chance to see a total eclipse of the Moon.

Lunar eclipses occur when the Moon passes through Earth's shadow. If the Moon only moves part of the way into that shadow we only see part of its bright face darkened - a partial lunar eclipse. If the Moon's orbit around the Earth takes it completely into the Earth's shadow then all of its bright face is darkened - a total lunar eclipse.

The good news is that this eclipse will be clearly visible to the naked eye and, unlike solar eclipses, will be perfectly safe to watch without using safety filters. The bad news is that it will take place at ridiculous o'clock in the morning when sane people are usually tucked up in bed fast asleep.

Although you'll be able to see the eclipse from your garden you'll have a much better view from somewhere away from light pollution with a clear view to the west and either side of it, because that's where the eclipsed Moon will be. Avoid sites with tall obstructions in that direction; although the Moon will be quite high when the eclipse starts, by the time it is fully eclipsed it will be fairly low in the west, and you wouldn't want to watch helplessly as the eclipsed Moon dropped out of sight behind a tree or a hill...

You should be at your observing site at least half an hour before the eclipse begins, and as the eclipse will begin at around half past three in the morning that means a very early start, so set several alarms to make sure you don't sleep through it. Dress for the extreme cold - hat, gloves, thick jacket, several pairs of socks - and take a flask with something hot to warm you up and some snacks.

> "Lunar eclipses occur when the Moon passes through Earth's shadow"

Tips & tricks

Dress sensibly

At silly o'clock on a January morning it will be bitterly cold, so wear your warmest hat, gloves and jacket. Some thick-soled boots are a must too. If you look like a polar explorer you're ready to go!

Find a good observing site

You'll have the best view of the eclipse from somewhere out in the countryside with a clear view of the sky. Scout out good dark-sky locations before the eclipse.

Be in place in good time

Be at your observing site at least half an hour before, then you won't miss the start of the eclipse because you're rushing around getting set up.

Take binoculars or a small telescope

You won't need either to see the eclipse, but they will bring out the beautiful orange, violet and lavender

Getting the perfect view

It's all about the timing when it comes to that memorable view of the blood Moon

The eclipse will begin at 3:33am when the Earth's shadow first falls on the Moon. It will then slowly advance across it from the top left of the disc until half the Moon is covered by 4:10. At 4:41 the Moon will be fully in Earth's shadow. What will it look like? We can't know in advance. Sometimes the fully eclipsed Moon is a bright tangerine-orange. Other times it is a much darker, muddy brown.

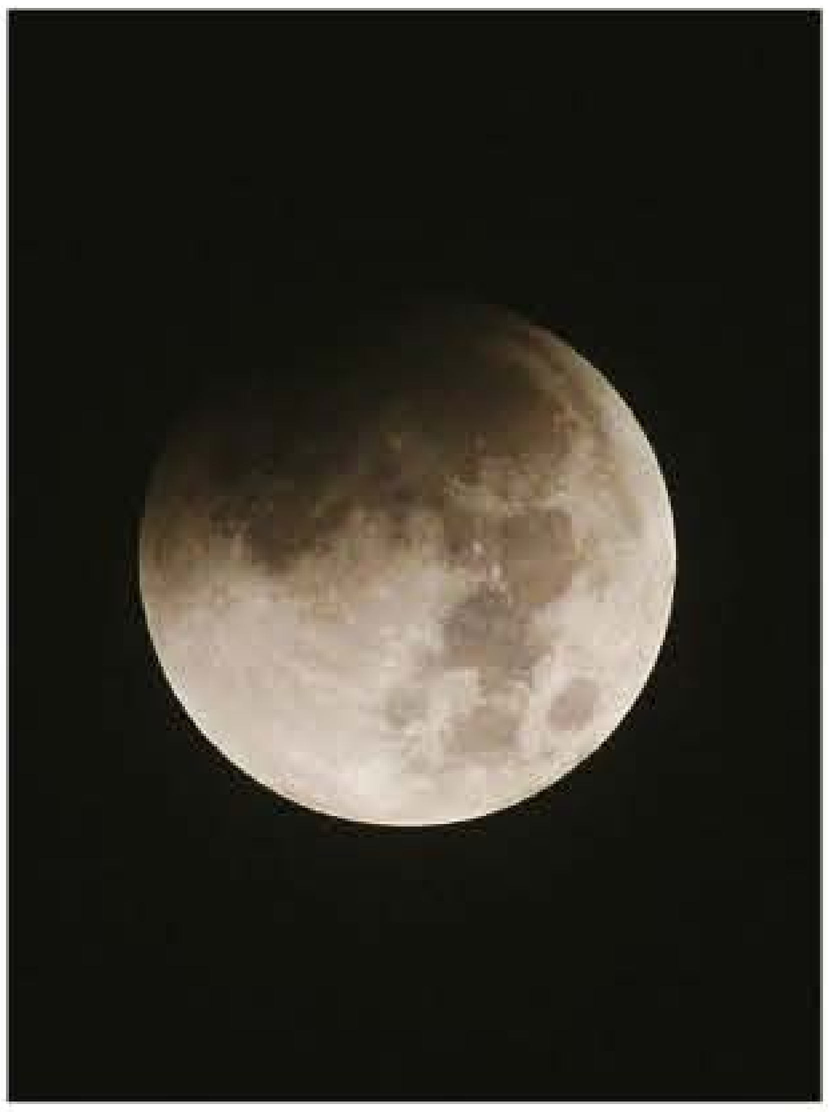
Send your photos to
space@spaceanswers.com

1 Wrap up warm

Make sure you are dressed in your warmest hat, gloves and jacket before heading out. If you feel cold you'll want to come home early, so wrap up as warm as possible.

2 Get a clear western horizon

Make sure your chosen observing site doesn't have anything on the western horizon which will hide the Moon during the later stages of the eclipse.



3 Look for 'First Contact'

Keep a close eye on the top left of the Moon for first contact at 3:33 - you might not notice the shadow until a few minutes later. You can then watch the colour of the Moon change!

4 Make the most of optical aid

If you have binoculars or a telescope look at the totally eclipsed Moon through them. They will enhance the lovely orange, violet and brown colours of totality.

5 Try shooting with a DSLR

Use a DSLR camera on a sturdy tripod to photograph the eclipse. You'll need a 200mm or longer lens to get a decent-sized image of the Moon.

6 Process your shots

Once you've slept and thawed out, process your images to bring out the beautiful colours of the totally eclipsed Moon. Be careful not to over-process them, though!

© Farhan Perdana (Blek); Dylan O'Donnell, deography.com

Flame Nebula (NGC 2024)

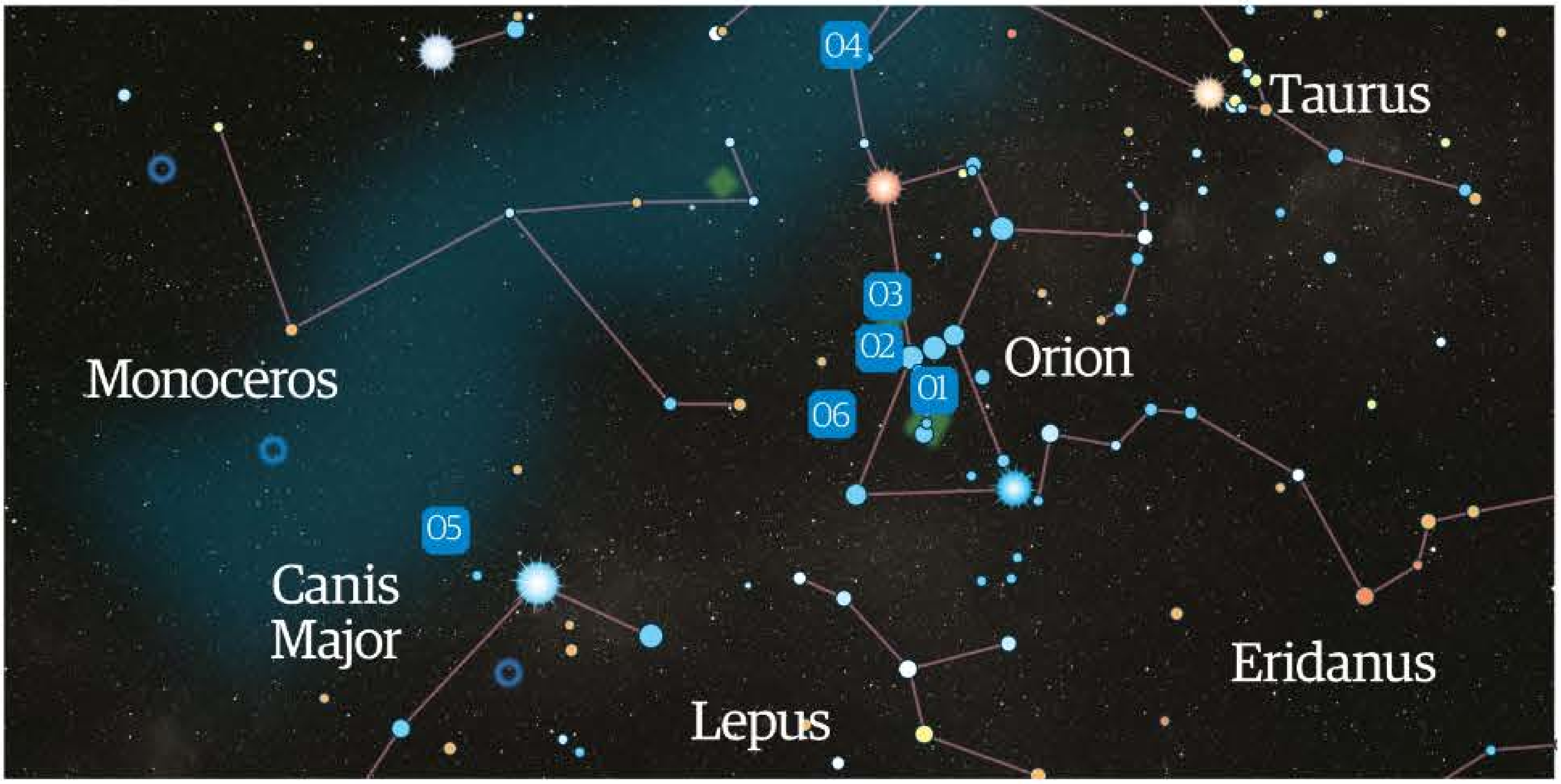
Unveil deep-sky treasures hidden in and around Orion

As gorgeous as it is, there's more to see in this part of the sky than the Hunter's nebula

When you take your telescope outside on a frosty, sparkling, clear January night and see the jewelled stars of Orion blazing in the south, it's tempting to swing it towards the same old targets you always look at in winter, especially the misty grey-green swirls and whorls of the beautiful Orion Nebula (M42), glowing softly in the centre of Orion's very short sword, hanging from his much more famous belt. That's understandable; after all it is one of the most stunning deep-sky objects in the whole of the sky. But if you take a deep breath and dare to drag your eyes away from this star-forming region, you'll find there are other treasures studding the area.

They are challenging to find, but once you've seen them with your own eyes you'll go back to them again and again. This month we'll show you how to find one of the most famous but elusive nebulae in the whole sky, a star cluster named after a famous female astronomer and a faint nebula very few people have even heard of. So wrap up warm, get yourself settled under a dark sky and get ready to enjoy the sights.

Caroline's Cluster (NGC 2360)



Messier 78

1 Horsehead Nebula (Barnard 33)

Few have actually seen it with their own eyes. You'll need a very dark sky and 6" or larger telescope to see it as dark 'notch' against a faintly glowing cloud of pale gas beneath Alnitak.

2 Flame Nebula (NGC 2024)

Also close to Alnitak, the Flame Nebula is a tenth-magnitude emission nebula that is best seen in 6" or larger scopes. Large-aperture instruments reveal it is cut across by several dark dust lanes.

3 Messier 78

Magnitude 8.3 M78 is bright enough to be visible in small telescopes, looking like a smudge of light, but because of its proximity to the glorious Orion Nebula it is viewed very rarely.

4 Lower's Nebula (Sharpless 261)

Hiding up near Orion's border with Gemini this small nebula is tenth magnitude but has a low surface brightness, so you'll need to use an 8" or larger telescope under a truly dark sky to spot it.

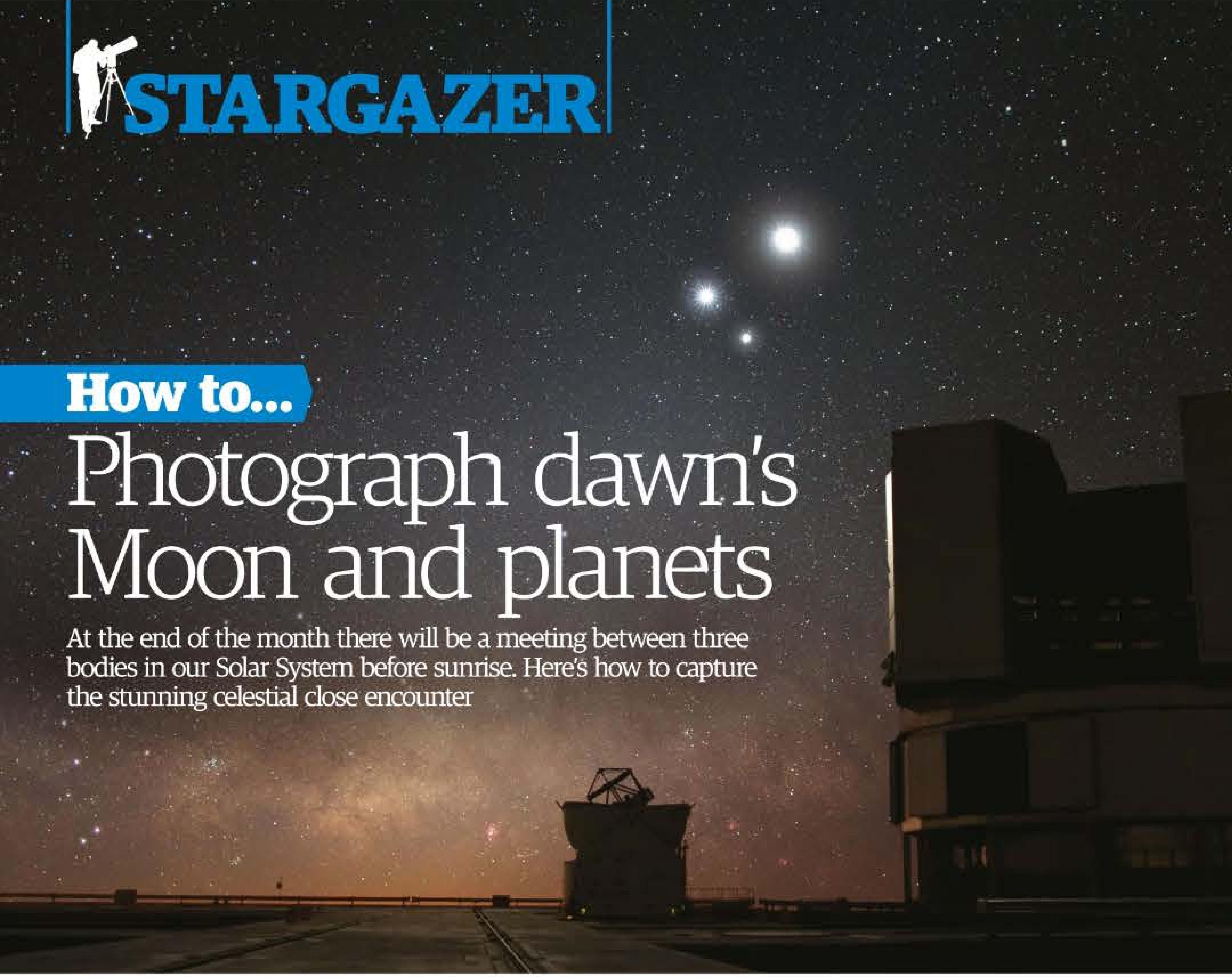
5 Caroline's Cluster (NGC 2360)

A seventh-magnitude open cluster, many say it is prettier than the bigger, brighter M41 star cluster that sits nearby beneath Sirius. Telescopes of 4.5" or bigger show it as a compact spray of blue-white stars very well.

6 HD 38858

It's worth tracking down this magnitude 6.4 star with your telescope just so you can look at it and know you're looking at a star with a planet orbiting around it. HD 38858b is twice Uranus' mass and lies in its stars habitable zone.

© ESO; ESA; Wil Tirion; Roberto Mura



How to...

Photograph dawn's Moon and planets

At the end of the month there will be a meeting between three bodies in our Solar System before sunrise. Here's how to capture the stunning celestial close encounter

You'll need:

- ✓ DSLR camera
- ✓ Sturdy tripod
- ✓ Cable release
- ✓ 50mm lens or wider
- ✓ Clear view to the southeast
- ✓ Computer with image-processing software

Cross your fingers for clear skies on the last two mornings of January; if the weather cooperates we'll be able to see something very pretty - a gathering of two bright planets and the Moon low in the southeast before sunrise. You'll need no special equipment to see this cosmic collection because all three objects are easily visible to the naked eye, but if you want to photograph it you will need a good camera on a tripod, and a suitable observing site too.

Seeing the Moon and planets will mean a very early start: aim to be at your observing site by 5:30am on the 30th. You'll see a beautiful waning crescent Moon low in the sky, with bright Jupiter down to its lower left. Down to Jupiter's lower left, just clearing the horizon, you'll spot Venus, much brighter than Jupiter.

With either a 50mm lens or a kit 18-55mm lens fitted to it, set up your DSLR camera on its sturdy tripod and point it towards the Moon and planets. With your camera set to Manual mode, set its ISO to 800 at first. Set the exposure length according to the lens you're using: 20 seconds for a wide-angle lens or five seconds for a 50mm. Finally, fit the camera with a cable release - essential for helping reduce vibrations - and then, with 'Autofocus' turned off, manually focus your camera sharply on either Venus or Jupiter. Then take your first photo by pressing the cable release.

Take a look at your first image and change your settings if necessary: increase the ISO if it's too dark, reduce the exposure time if the Moon and planets are burned out. Then just experiment with different combinations of settings until you're happy with the result. Then, keeping those settings, wander around your site taking photos of the Moon and planets with different foregrounds to add variety - taking exactly the same image again and again will be boring.

Back home, be careful not to over-process your images. Just do enough processing to show the different colours of Jupiter and Venus and the Moon's slim crescent.

> "Seeing the Moon and planets will mean a very early start"

© ESO

Tips & tricks

Find a suitable observing site
Make sure your observing site has a clear, low southeast horizon. Any trees, buildings or hills in that direction will hide the Moon and planets from view.

Use a cable release
Using a cable release instead of your finger to begin your exposures will further reduce vibrations and ensure your photos are sharp and in focus.

Get the right lens
A standard 50mm lens or a basic 18-55mm 'kit' lens will be fine for photographing this planetary gathering. Zoom lenses will not be able to fit everything in.

Take lots of photos
Take as many photos as you like, capturing how the view changes as the morning sky brightens and the Moon and planets climb higher above the horizon.

Get that perfectly aligned photo

It'll be an early start, so here's how to create that shot to be proud of

If your sky is cloudy before sunrise on 30 January you've got another chance to try again the next morning. The Moon will still be close to Jupiter and Venus and the view might actually be more photogenic because the very slim crescent Moon will be between the two planets - a much more striking arrangement. If you're dedicated you can take snaps both mornings and compare their positions.

Send your photos to
space@spaceanswers.com

1 Carefully select a site

Choose your observing site carefully - make sure no trees, buildings or hills will block your view of the meeting of the Moon and planets.

2 Use a sturdy tripod for your digital camera

Mount your DSLR camera securely on a sturdy tripod. Fit it with a cable release and either a 50mm or 18-55mm lens (or equivalent).

3 Use a planet for focus

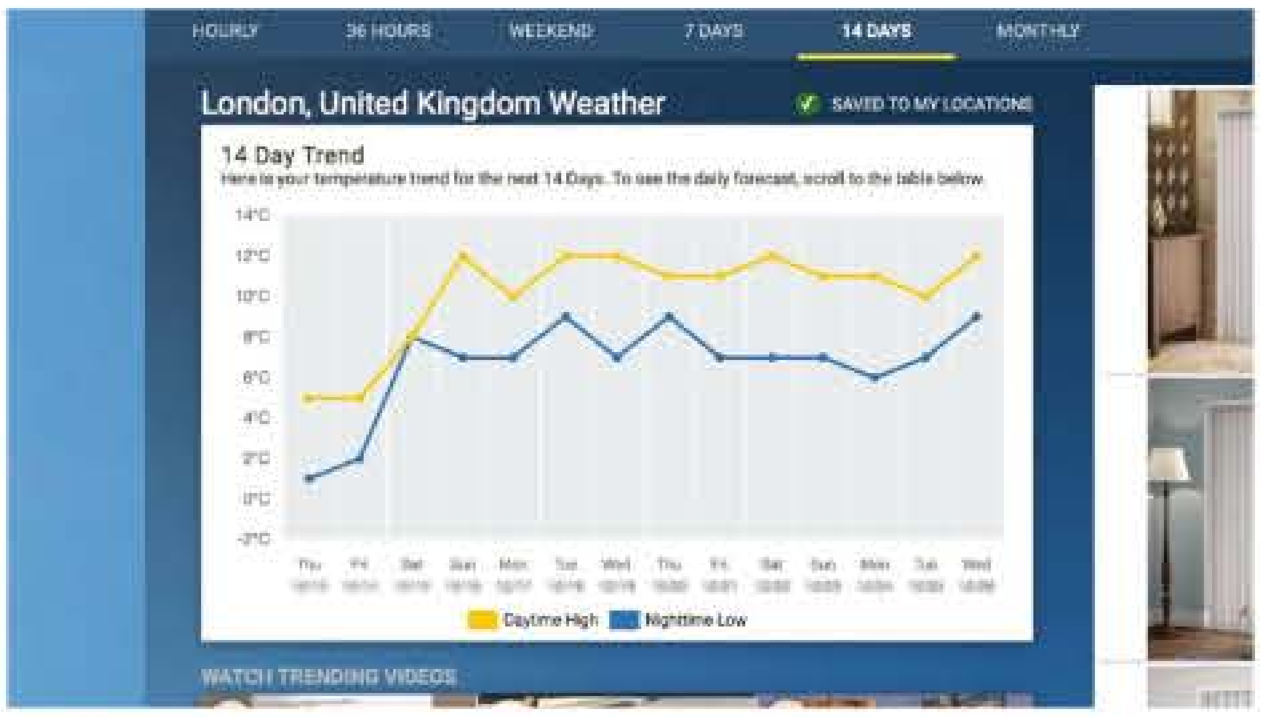
After focusing on either Venus or Jupiter and using the settings suggested opposite, take a test shot. Change your camera settings if necessary.

4 Take time to admire the spectacle

Take lots of photos, but make sure you spend some time just looking at the Moon and planets with your naked eye or a pair of binoculars.

5 Be wary of over-processing

Back home, after catching up on sleep, process your images on your computer but be careful not to over-process them and spoil them.



London, United Kingdom Weather

14 Day Trend

Here is your temperature trend for the next 14 Days. To see the daily forecast, scroll to the table below

6 Remember other opportunities

If the 30th is cloudy, remember the view the next morning will be as good, and maybe even better, so try again on 31 January.

© Google Maps; Ed Dunens

The Northern Hemisphere

The New Year has arrived with some of the very best night-sky targets, studded in long winter nights

Whether you just got your first telescope for Christmas or you've long been observing, there are some wonderful targets to seek out in the New Year. Orion (the Hunter) and Taurus (the Bull) remain prominent in the sky, offering splendid sights including red supergiant Betelgeuse, brilliant blue-white Rigel, the Pleiades star cluster (Messier 45), orange giant Aldebaran and of course, the Crab Nebula (Messier 1). Look southeast and you'll spot a celestial Great Dog: a seemingly basic-looking pattern of stars, Canis Major features several binary systems and supergiant stars. It's also home to open cluster Messier 41, which contains an impressive collection of red giants and white dwarfs, not too far from 'Dog Star' Sirius.

Using the sky chart

This chart is for use at 10pm (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

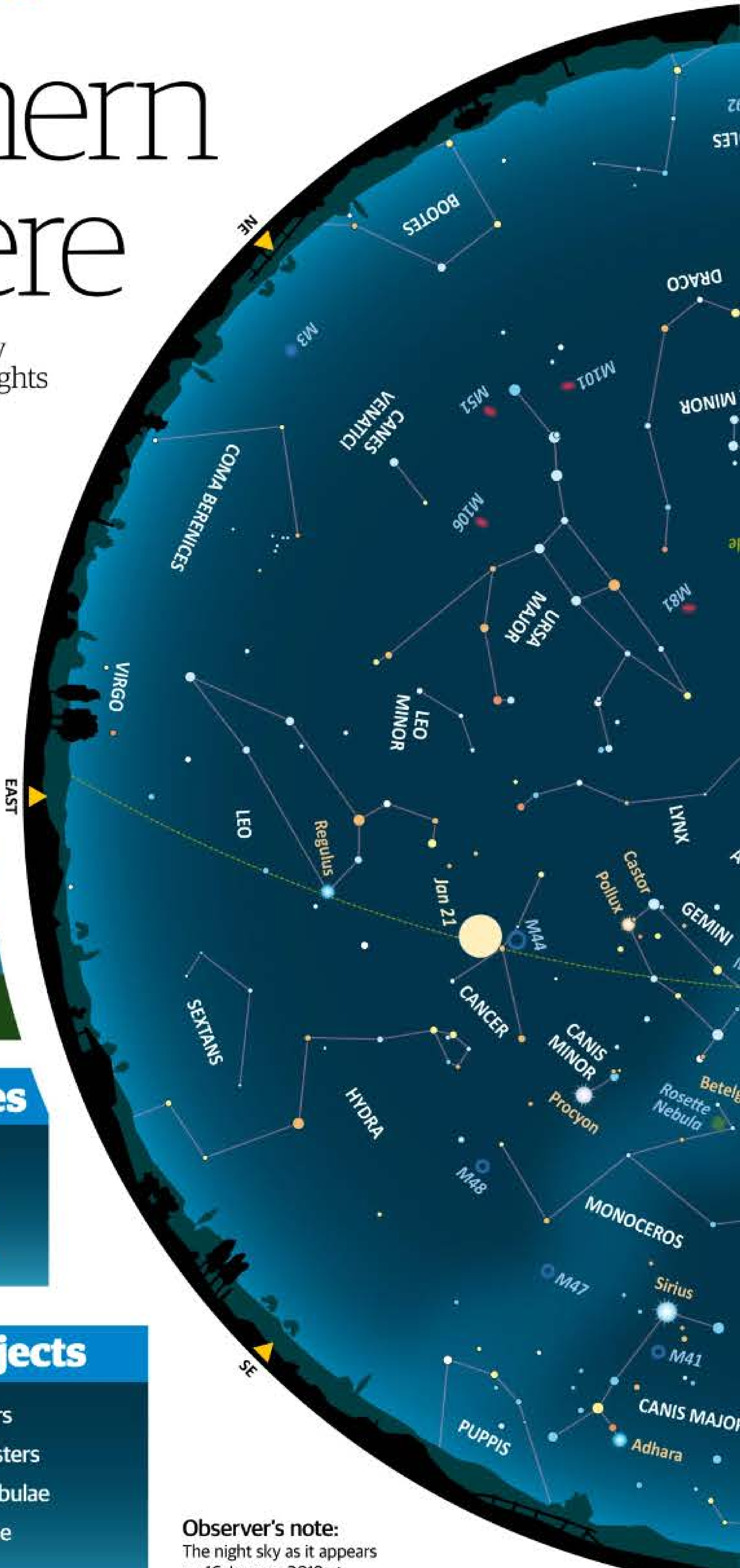
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

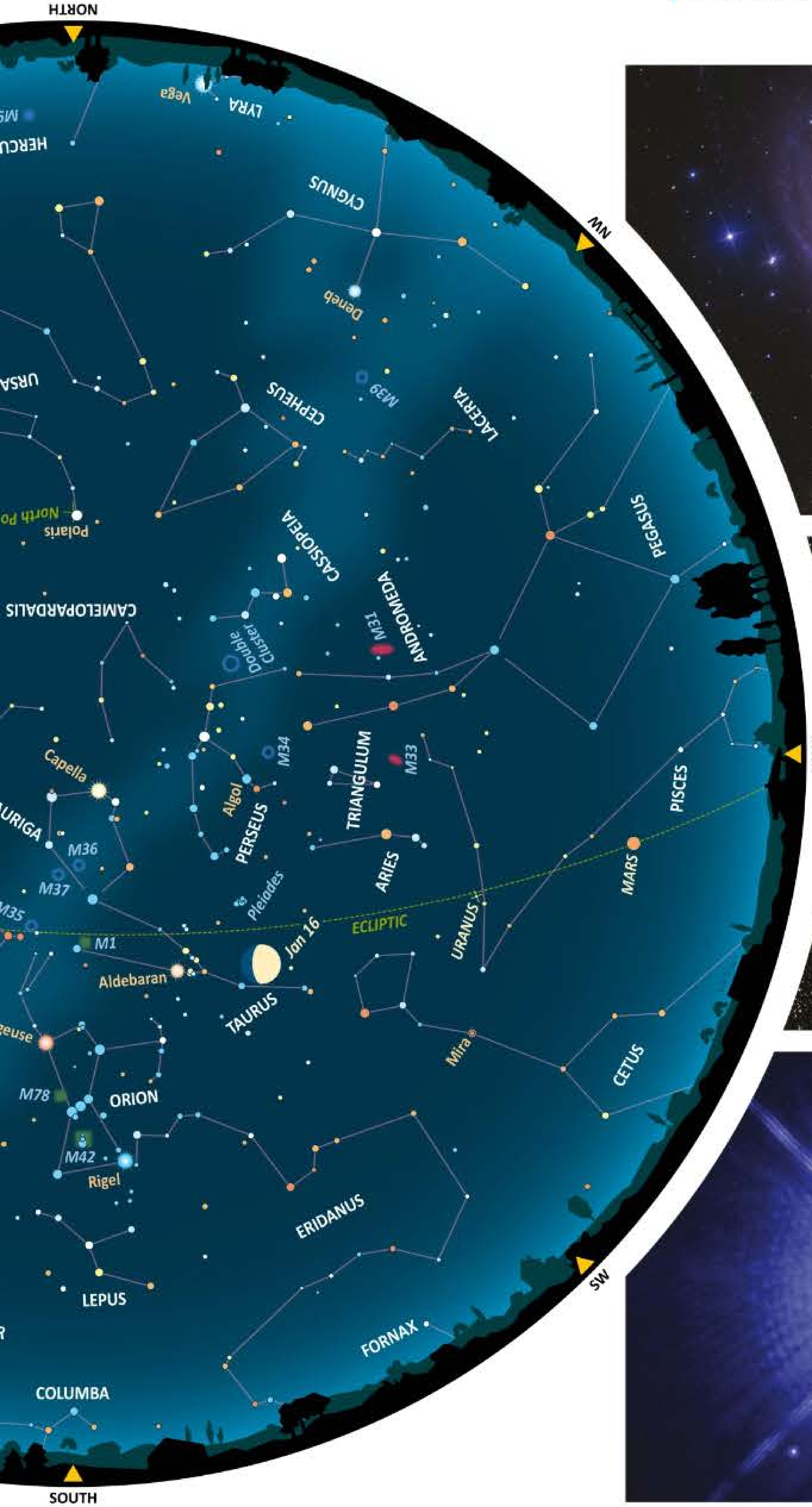
● O-B	● G
● A	● K
● F	● M

Deep-sky objects

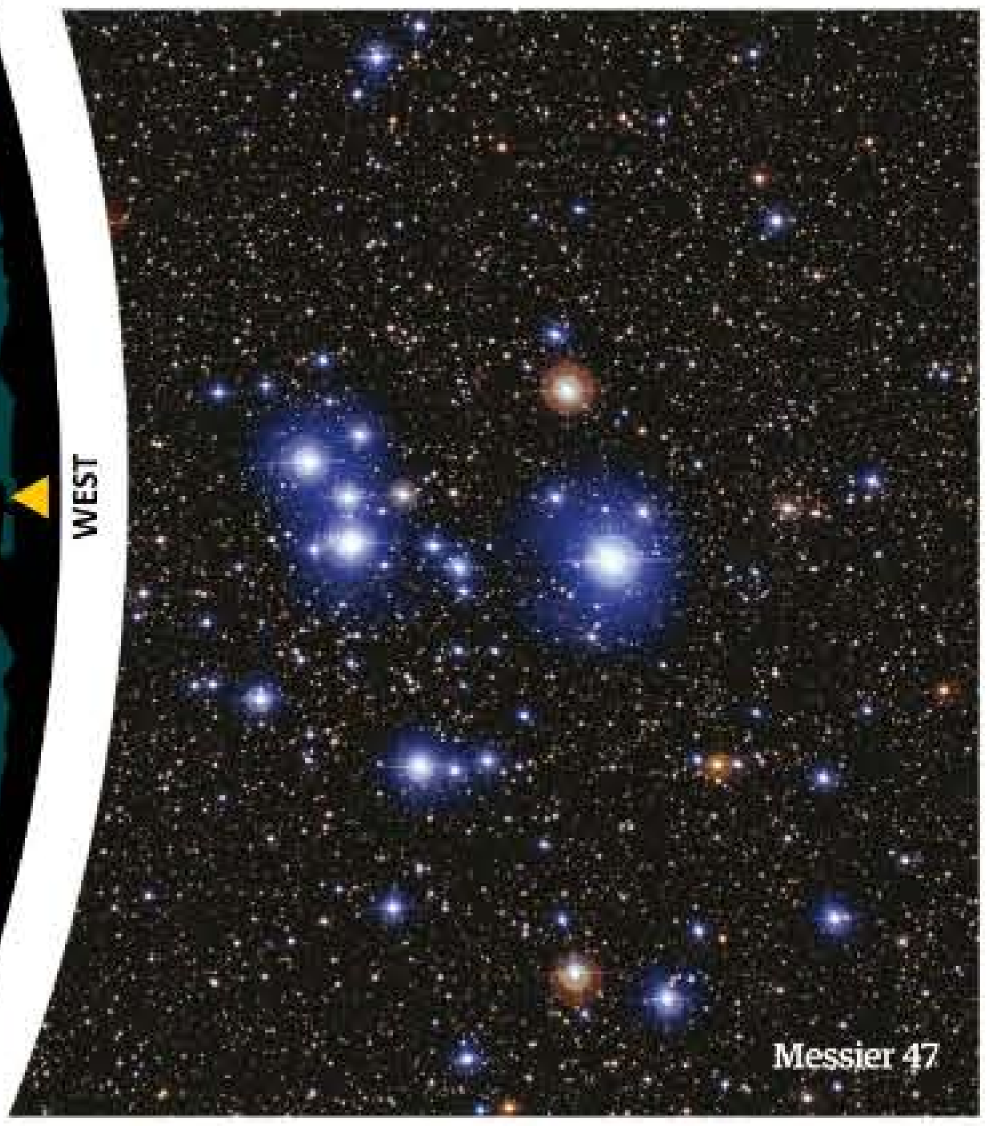
- ○ ○ Open star clusters
- ● ● Globular star clusters
- ■ ■ Bright diffuse nebulae
- ○ ○ Planetary nebulae
- ● ● Galaxies

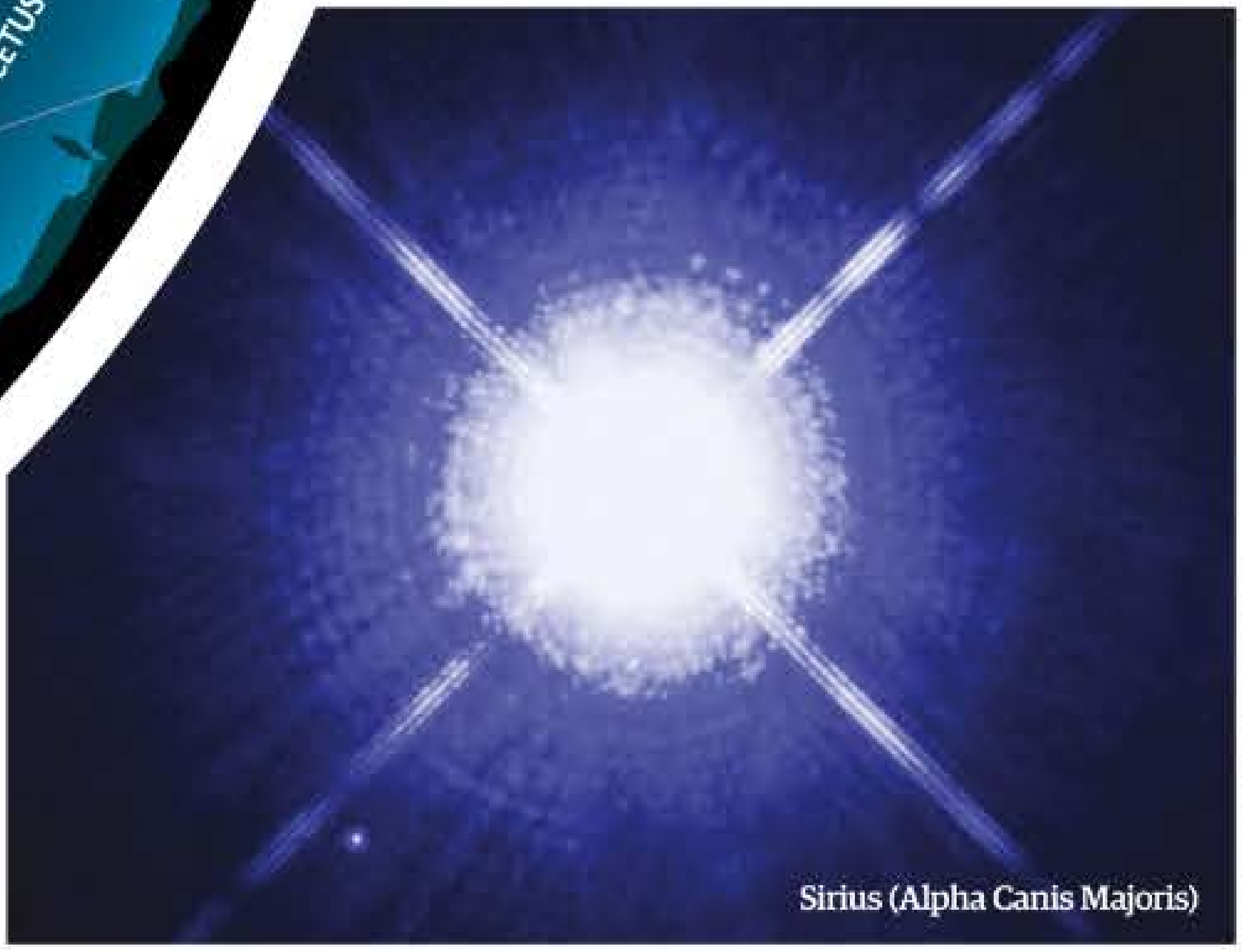


Observer's note:
The night sky as it appears on 16 January 2019 at approximately 10pm (GMT).



Bode's Galaxy (Messier 81)

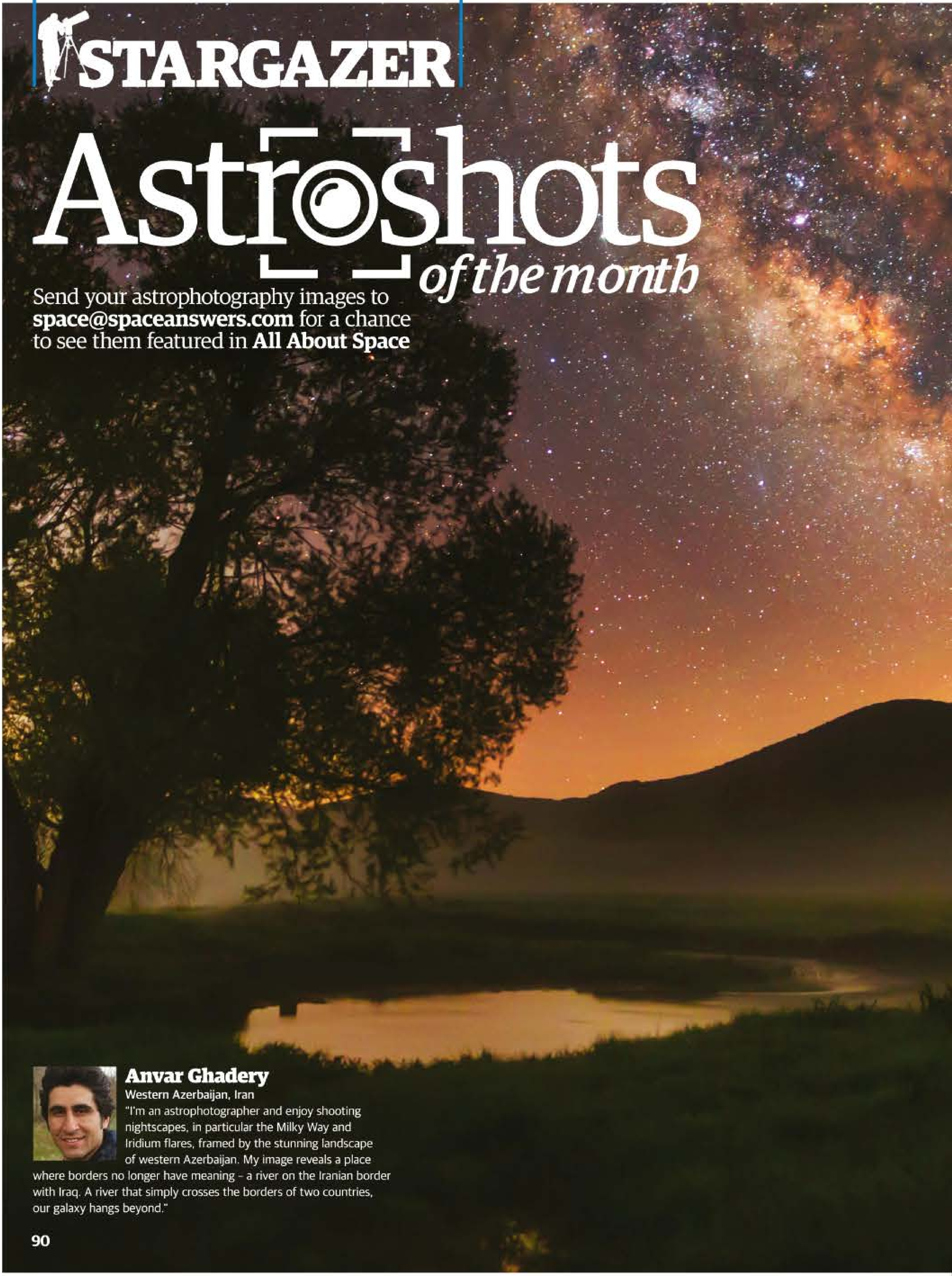

Messier 47


Sirius (Alpha Canis Majoris)

© Will Tirion; NASA/ESA; ESO; Ken Crawford;

Astroshots of the month

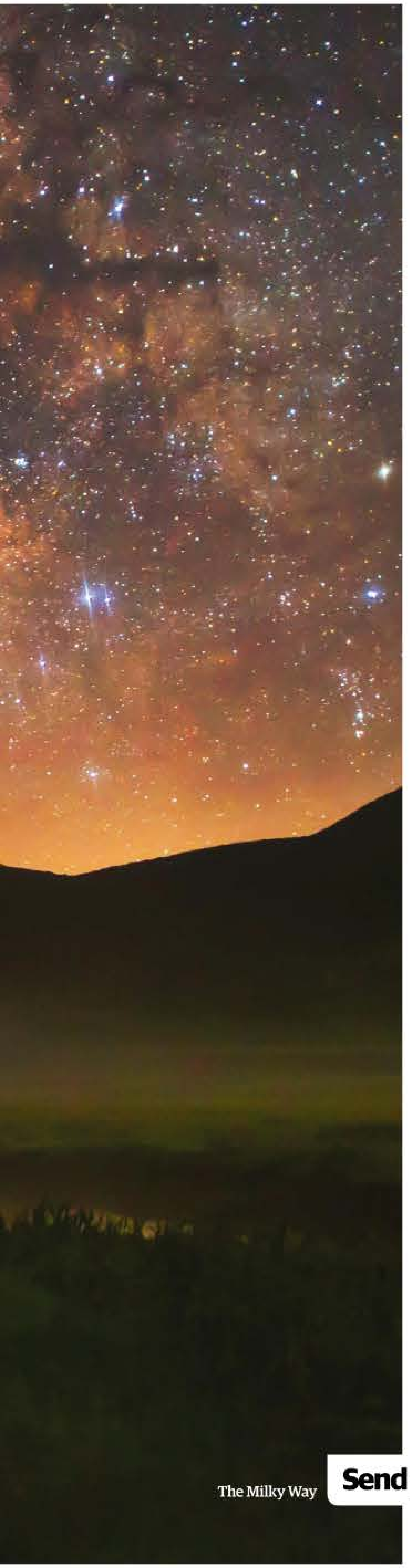
Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**



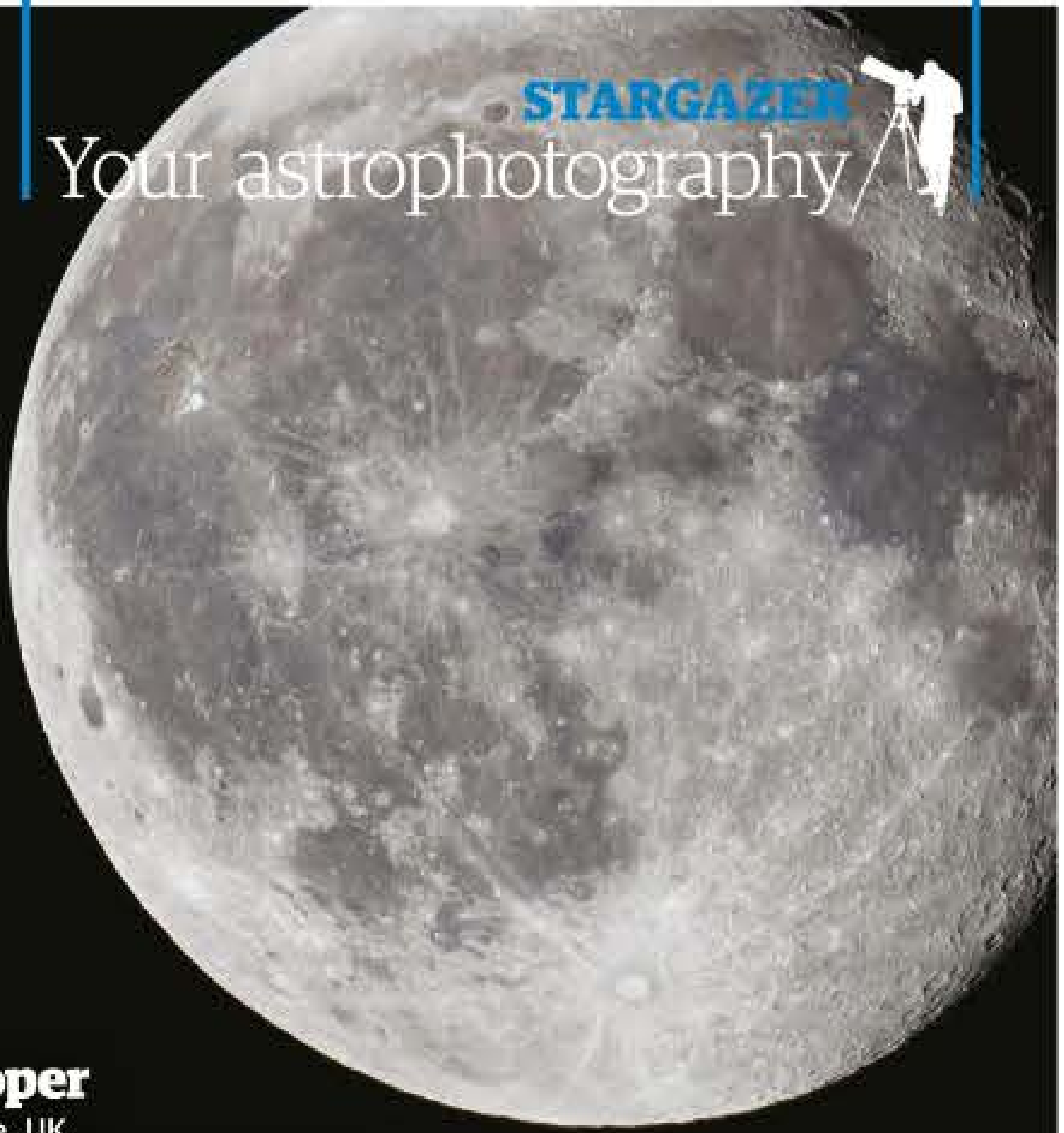
Anvar Ghadery

Western Azerbaijan, Iran

"I'm an astrophotographer and enjoy shooting nightscapes, in particular the Milky Way and Iridium flares, framed by the stunning landscape of western Azerbaijan. My image reveals a place where borders no longer have meaning – a river on the Iranian border with Iraq. A river that simply crosses the borders of two countries, our galaxy hangs beyond."



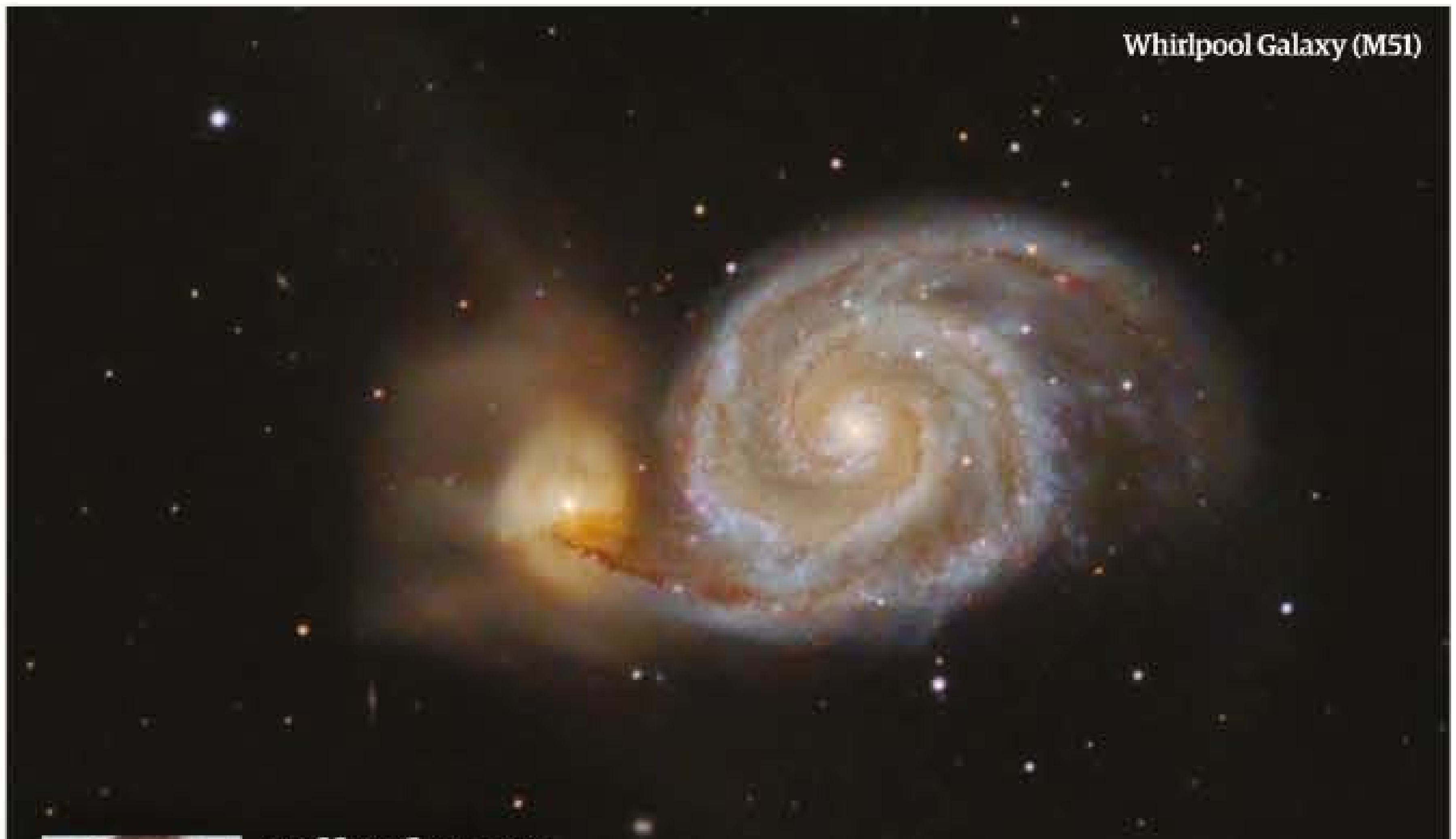
The Milky Way



Jamie Cooper

Northamptonshire, UK

"I first became interested in astronomy as a boy when my father, who was a keen amateur astronomer, first showed me the amazing views that could be seen through a backyard telescope. There was something magical for a small boy seeing mountains and craters in fine detail on the Moon. The first views of Saturn with its rings and Mars with white polar caps and areas of different-coloured terrain left an indelible mark on me as a child. Over the years I have travelled the world searching for some of the most wonderful sights in nature to observe and photograph such as solar eclipses, comets and displays of the northern lights."



Whirlpool Galaxy (M51)

Jeff Johnson

Las Cruces, New Mexico

Telescope: Takahashi TOA-130F

"My latest results, which were imaged from my backyard in Las Cruces, features the Whirlpool Galaxy, also known as Messier 51, in the constellation of Canes Venatici. I have a long love of astronomy and have observed the night sky for many years with binoculars and a telescope from the age of ten. I did my first 'real' astrophotography in 1996 when I used a 35mm SLR camera to take photos of Comet Hyakutake. I took a tripod out into the desert here in Las Cruces and just experimented with exposures. Later, I bought a 10-inch dobsonian for viewing, and within a week I was taking pictures through the eyepiece for fun. Within a few more weeks I knew I wanted to get serious with astroimaging."

Send your photos to... @spaceanswers space@spaceanswers.com

Takahashi FS-60C

Exuding quality, this apochromatic refractor is of exceptional optical and mechanical performance - perfect for the intermediate astronomer

Telescope advice

Cost: £665
From: Rother Valley Optics Ltd
Type: Refractor
Aperture: 60mm
Focal length: 355mm

From the moment we unpackaged the Takahashi FS-60C we were in awe of its superb quality; with its pearly white finish, complete with the classic green accents on the lens cover and focuser that manufacturer Takahashi are famous for, this refractor is an impressive piece of workmanship. Of course, being an apochromatic means that you're getting the best in telescope optics - boasting superb clarity and contrast and a way of keeping colour-fringing, also known as chromatic aberration, at bay - and lending itself to a high retail price for the tube alone. However, if you're an astronomer who is on the hunt for the very best views of the night sky and you're serious about a hobby in astronomy for many years to come, then we think it's a great investment, as you'll discover here.

Takahashi has ensured that you can also purchase the best in accessories for the FS-60C and offer two clamshells with an internal diameter of 80mm that can be combined with the tube. The narrower clamshell has a small foot that makes mounting the tube a breeze, offering great balance for the scope, which we found to get quite back heavy when we plugged a large 2" eyepiece into the holder. You will need to purchase an adapter from Takahashi in order for an accessory of this aperture to fit.

The Takahashi FS-60C makes use of an air-spaced doublet lens, where the front element is fabricated from fluorite and the rear negative element utilises an eco-glass, both of which work in unison to ensure that light is not scattered as much compared to other telescopes. This aids the highest contrast views - something that's very important when observers are trying to tease out the last bit of detail allowed by atmospheric conditions. Meanwhile, the quality of the anti-reflective coating was exquisite when we shone

Right:
The optical performance is exquisite, boasting lack of scattered light and extreme contrast in the image

Below:
The telescope exudes high-quality, right down to its 'nuts and bolts'

a bright light into it, and stray light is controlled very well by black paint and a baffle half way down the tube. The optics allow for serious astrophotography, however, as with most scopes intended for imaging, the telescope's drawtube is quite short being one inch in length – there's a method to this though; this ensures that the light path is not cut into when the focus is racked in – speaking of the focuser, we found its operation to be smooth, however, does not have the finer control of a micro-focuser.

The general rule among astronomers is that a telescope of 355mm or less in focal length doesn't really need a finderscope. Even so, for that added simplicity of navigating targets, we recommend making good use of the 6x30 finder – which accounts for 18 degrees on the night sky – that comes supplied with the instrument. What's more, it's included with a mounting plate for easy attachment. Generally speaking the finder is of fine quality, despite not being finished to the same quality of the tube and the excellent lens coating.

Early December gave us some great nights of observation – that is, compared to November, which saw us having to forfeit touring the night sky and wait for the copious amounts of cloud and rain to clear. We immediately got stuck into a star test – of which the member stars in the belt of Orion made for easy pickings – and are pleased to report that we only detected a small pink-magenta colouration in the outer Fresnel ring when we brought the telescope into focus and a slight pale green colouration when we brought our target stars out of focus. With a focal ratio of f/5.9 we are treated to a focal plane that's actually quite razor thin.

It's true that the telescope isn't completely free of chromatic aberration, but that's a tall order given the focal length. Even so, there was no chromatic aberration on Jupiter or the Moon, even at 150x plus, though occasionally we wondered if we were seeing a very slight magenta hue in the inky-black shadows of lunar craters at very high magnifications. Waiting for Venus in the dawn sky and some challenging bright stars such as Sirius and Vega have shown a modest amount of false colour, especially in the first diffraction ring. Despite this we'd argue that it has never spoiled the view.

> "The most satisfying element has been the lack of scattered light and extreme contrast"

The most satisfying element of the optical performance has been the lack of scattered light and extreme contrast in the image. The sky around the edge of a bright Moon and surrounding the planets is jet black thanks to the fluorite's advantage of low light scatter. Jupiter shows a remarkable amount of low contrast surface detail. The Great Red Spot and shadow transits are not beyond the reach of the FS-60C as are transits of the Galilean moons themselves.

The excellent contrast, which allows the scope to perform well on the planets, also translates into surprising deep-sky performance, especially under dark skies, where it belies its 60mm aperture. As well as presenting some of the showpiece objects of the night sky very well, showing a green hue and plenty of detail in the Orion Nebula and some structure in larger globular clusters such as Messier 13, the scope reveals unexpected amounts of detail in a wide variety of nebulae and clusters to the patient and experienced observer. Moving over to galaxies of low surface brightness did pose a slight challenge for this small Takahashi – in this sense, we advise users to lower the magnification.

A remarkable piece of kit given its size, the Takahashi FS-60C is fun to use and gives you some awe-inspiring sights of the night sky. It doesn't come with many accessories, but given the exquisite optical system and its lightweight 'grab and go' design, we feel that the cost is certainly worth it.

Above: You will need to purchase an adapter from Takahashi in order for an accessory of larger than 1.25" to fit

Below: The Takahashi FS-60C operates smoothly in and out of focus

Best for...

- ? Intermediate
- £ Large budget
- Solar System targets
- Lunar imaging
- Deep-sky
- Astrophotography

WIN AN OMEGON ADVANCED N 203/1200 DOBSONIAN

This all-rounder telescope is suitable for observing both Solar System and faint deep-sky targets – and we're giving one away, courtesy of **astroshop.eu**

WORTH £800!

Treat your eyes to a new window into the universe. The Omegon Advanced N 203/1200 Dobsonian offers clear views of planets, nebulae and galaxies, and even at high magnifications navigating the rocker-box mount to any object in the night sky is quick and easy.

Featuring exquisite optics and an aperture of 203mm, the telescope's parabolic main mirror lends itself to sharp and bright images right across the field of view, allowing you to take a tour of the planets of the Solar System with clarity and get up close to the sparkling stars of tightly packed globular clusters and galaxies beyond our Milky Way. And that's not all – the Omegon Advanced N 203/1200 also allows you to achieve stunning views of comets, nebulae, planetary nebulae and open clusters.

With the Omegon Advanced as part of your observing kit you'll always be at an advantage – you can get observing immediately with the supplied 10mm and 25mm eyepieces and red dot finder and always tour the night sky with a sturdy, smooth set-up thanks to a new friction system that balances those heavy eyepieces and other such accessories with ease.

To be in with a chance of winning, all you have to do is answer this question:

Who first argued that galaxies were 'island universes' in the Great Debate of 1920?

A: Heber Curtis

B: Edwin Hubble

C: Harlow Shapley

Competition ends on 1 February 2019

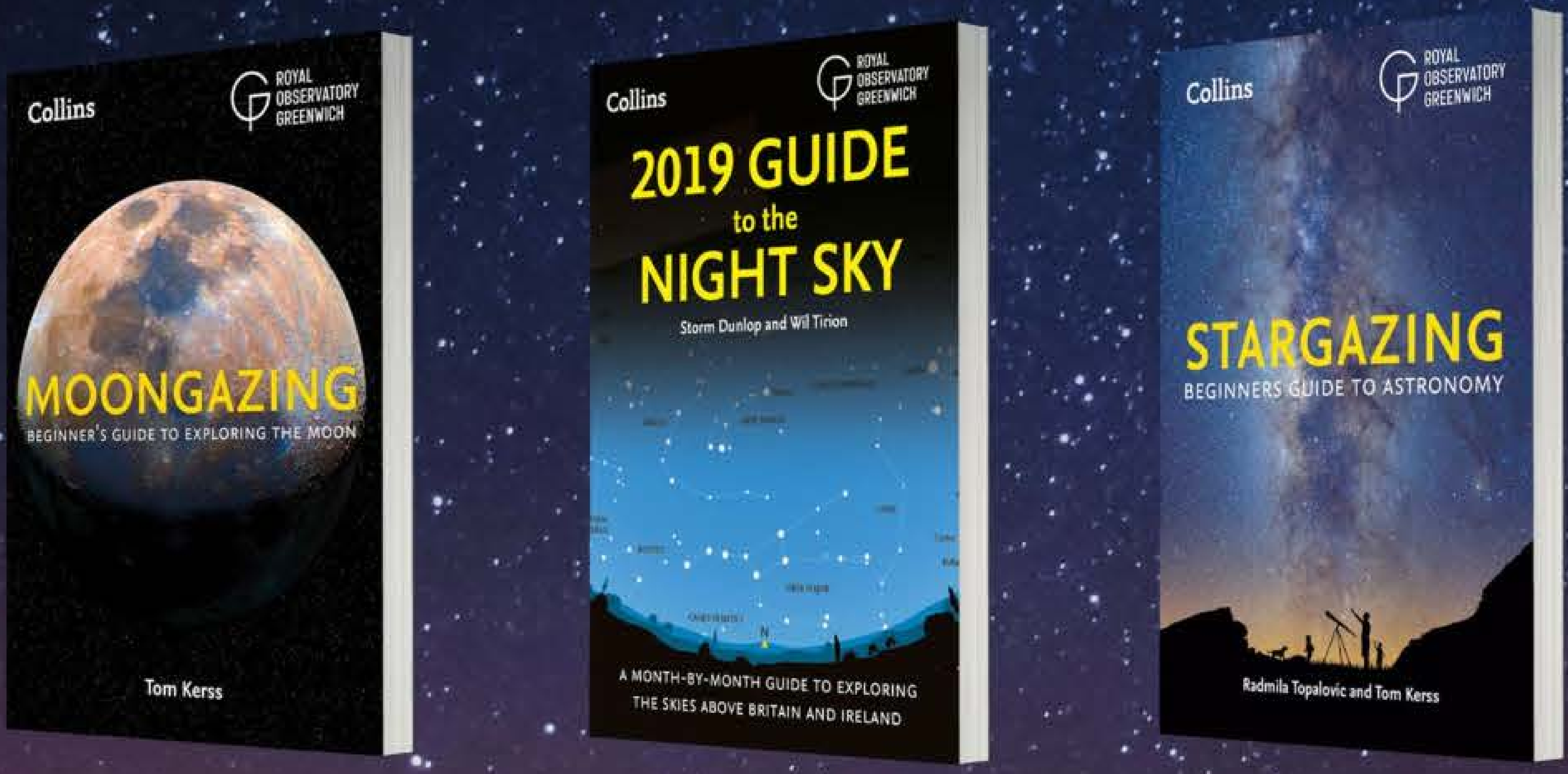
Enter via email at **space@spaceanswers.com** or by post to **All About Space competitions, Richmond House, 33 Richmond Hill, Bournemouth, BH2 6EZ**

Visit the website for full terms and conditions at **www.spaceanswers.com/competitions**

Collins

ROYAL OBSERVATORY GREENWICH

Look to the stars in 2019



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Radmila Topalovic and Tom Kerss

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1. Book How to Live in Space

Cost: £16.99 (approx $21.50) **From:** Andre Deutsch Ltd
With missions to the Moon and Mars planned in the near future, frequent **All About Space** writer Colin Stuart describes the practicalities and difficulties of living beyond Earth. Making use of infographics and images, Stuart's book is split into four parts. The first section is an introduction to space travel, looking at its history from Yuri Gagarin through to astronauts living on the International Space Station, explaining how we get into space with powerful rockets. Next up is a chapter describing astronaut training, detailing everything from how astronauts are selected, to what it is like to go on a centrifuge or the famous 'Vomit Comet' aeroplane for zero-gravity training, to actually getting into space and docking with the ISS. The third part looks at how astronauts live in space, from eating and drinking to the inevitable description of how astronauts go to the toilet, and more straight-faced fare such as protection from solar radiation. Finally, the books ends with a look to the future and how astronauts will experience new missions to the Moon, Mars, asteroids and perhaps, one day, interstellar travel.

2. Finderscope Omegon red dot finder

Cost: £17.90 (approx $22.70) **From:** omegon.eu
Finding a desired celestial object through the eyepiece of your telescope can be difficult; your field of view through the eyepiece is usually quite narrow, and if you're using a reflecting telescope the image is also upside down. Finderscopes, which are low- or zero-magnification pointing devices attached to the tube of your telescope, are the answer. This red dot finder from Omegon makes things even easier. It sports a frosted glass panel with zero magnification, meaning it shows the sky as it actually is, upon which a red LED dot is superimposed. Simply align the red dot with whatever you want to look at in the sky – say the planet Jupiter – and hey presto, your telescope will then also be aligned with Jupiter, saving you the task of nudging your 'scope around looking for it. Omegon's red dot finder is made for use on Sky-Watcher, Celestron and Vixen brackets that can attach to any telescope, and features a dimming function so you can make that red dot as bright or as faint as you are comfortable with just by turning a knob.

3. Eyepiece Omegon Super Wide Angle

Cost: from £90-£126 (approx $114-160) **From:** omegon.eu
Super-wide angle (SWA) eyepieces provide really wide views of the night sky, perfect for taking in extended deep-sky objects such as galaxies, nebulae and star clusters. This revamped range of SWA eyepieces from Omegon sport grippable rubber armour, a more comfortable eyecup with eye relief suitable for glasses-wearers, internal baffling to reduce light scatter and high-definition views all the way to the edge of the field, with barely any distortion to the image.

There are six eyepieces in the range, with focal lengths of 38mm, 32mm, 26mm, 20mm, 15mm and 10mm. The 38mm, 32mm and 26mm have two-inch barrel diameters and enormous true fields of view. The 20mm, 15mm and 10mm varieties have 1.25-inch barrels. Their 70-degree apparent field of view means you'll feel like you're floating among the stars in no time.

4. App NASA Space Images

Cost: Free **From:** iTunes/Google Play

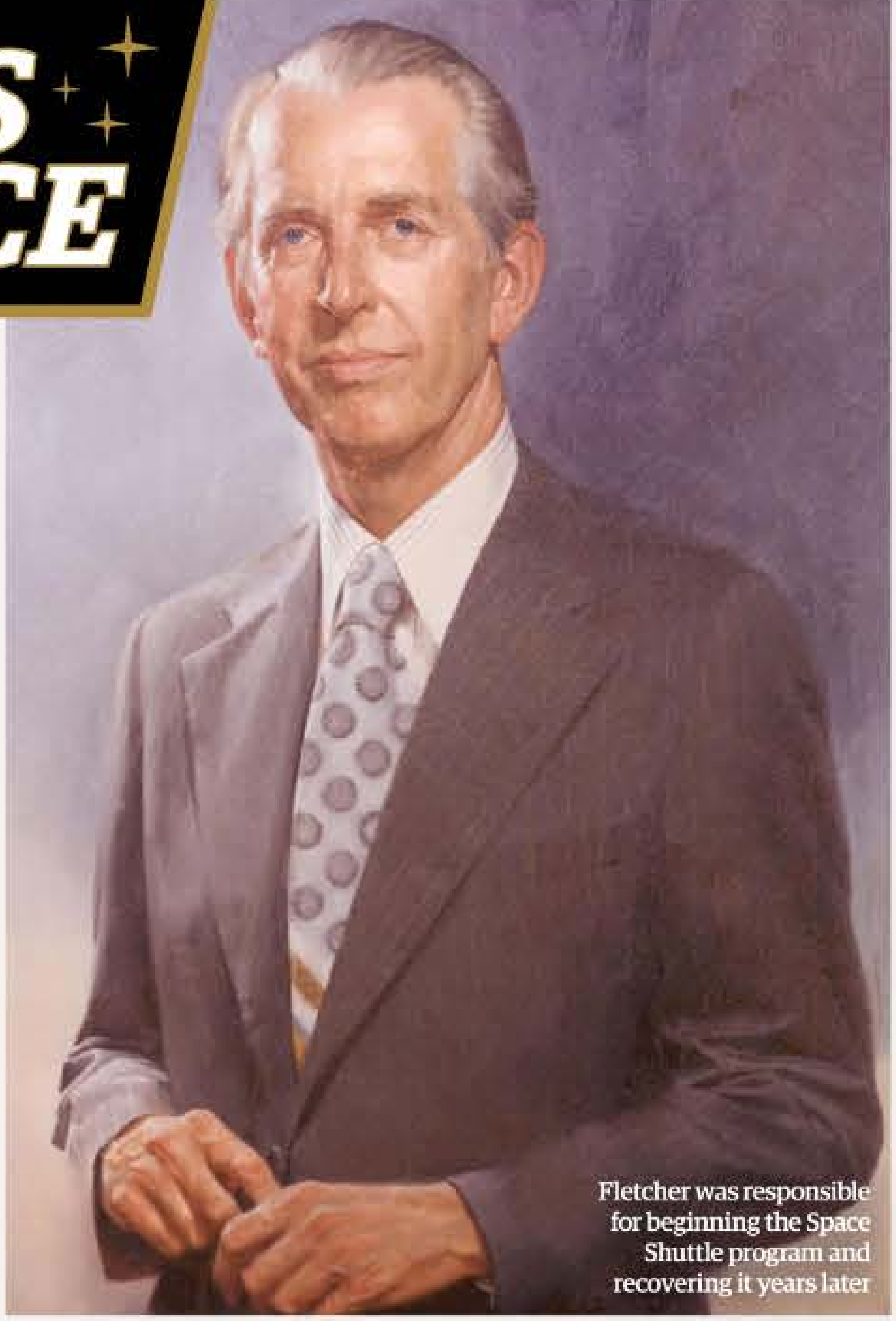
NASA's various space missions, from the Hubble Space Telescope to New Horizons, produce a vast amount of wonderful space imagery, and now they've all been wrapped up together in this third version of NASA/JPL's Space Images app. Features include the ability to share images from the app on social media, save the best images to your favourites folder, turn images into backgrounds or wallpapers for your devices, browse through hundreds of images and videos with detailed captions describing each image and a comprehensive search mode. The app works in conjunction with the Jet Propulsion Laboratory's new Space Images website at jpl.nasa.gov/jplimages. Best of all this app is free, so there's no excuse not to download it and start sharing wonderful images of the cosmos.

"Their 70-degree apparent field of view means you'll feel like you're floating among the stars in no time"

HEROES OF SPACE

James C. Fletcher

The only man to serve twice as the highest ranking person at NASA



Fletcher was responsible for beginning the Space Shuttle program and recovering it years later

A lot of the most influential programmes to come from NASA have done so thanks to the guidance and leadership of Dr James Chipman Fletcher, the most notable of which was the Space Shuttle program.

Born on 5 June 1919 in Millburn, New Jersey, United States, Fletcher was educated to a high standard, gaining a PhD in physics from the California Institute of Technology (Caltech), United States. He then entered research and teaching roles at both Harvard and Princeton University prior to joining Hughes Aircraft in 1948, also having a stint at the Guided Missile Division of the Ramo-Wooldridge Corporation.

This background in science, aircraft and aerospace made Fletcher well equipped to take on the task of NASA administrator, and he was sworn in to his first spell on 27 April 1971 by President Richard Nixon. Given this new responsibility, Fletcher's standout target was to establish the Space Shuttle program, the succeeding initiative to the Apollo program. Having to fill these enormous shoes was not an easy task, but the benefits that have arisen from the Space Shuttle program are testament to a job well done. Fletcher was also administrator during the three Skylab missions in 1973 and 1974 and the Viking mission that put two orbiters and two landers on Mars in 1976.

1 May 1977 marked the end of Fletcher's first spell as administrator, then having worked under a trio of presidents – Jimmy Carter, Gerald Ford and Nixon. For nine years Fletcher became an independent consultant in McLean, Virginia and advised key national leaders involved in planning space policy. He also took his skill set to the advisory board in developing the Strategic Defense Initiative.

On 28 January 1986 the world was shocked as the tragic Space Shuttle Challenger disaster occurred, claiming the lives of seven crew members. Ronald Reagan, who was president at the time, selected Fletcher for NASA administrator again a few months later as he aimed to recover the Space Shuttle program, pulling it out of the two-year hiatus that cast many doubts on whether it would get flying again. However, Fletcher oversaw the thorough analysis and revamping of the Space Shuttle, including redesigning the solid rocket boosters, an exit method for astronauts and a complete rework of components that boosted the safety and reliability.

Although recovering the Space Shuttle program from the brink was his main effort during his second spell, he also improved efficiency of the organisation and introduced a new management system. Other programmes that Fletcher initiated over his two spells include the construction of the Hubble Space Telescope, the approval of the Voyager space probes and the Apollo-Soyuz Test Project, a collaboration of the efforts of the United States and Soviet Union in space exploration.

Fletcher's second and final spell as NASA administrator ended on 8 April 1989 under President George H.W. Bush. Sadly, on 22 December 1991, Fletcher passed away at the age of 72 due to lung cancer, but his legacy surely lives on.

Fletcher's first spell as NASA administrator came from Richard Nixon in 1971

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Future PLC Richmond House, 33 Richmond Hill,
Bournemouth, Dorset, BH2 6EZ

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
01202 586209
Art Editor **Jonathan Wells**
Staff Writer **Lee Cavendish**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **James Sheppard**

Contributors
Stuart Atkinson, Meghan Bartels, Samantha Matthewson, Jonathan O'Callaghan, Tereza Pultarova, Nola Taylor Redd, James Romero, Hanneke Weitering

Cover images
Tobias Roetsch; Adrian Mann, K.M.Gill

Photography
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Advertising
Media packs are available on request
Commercial Director **Clare Dove**
clare.dove@futurenet.com
Regional Advertising Director **Mark Wright**
mark.wright@futurenet.com
Account Director **Andy Baker**
andy.baker@futurenet.com
01225 687 520
Account Manager **Jagdeep Maan**
jagdeep.maan@futurenet.com
01225 687 353

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Rachel Shaw licensing@futurenet.com

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SRP £299
Prod.Code 10270

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SRP £159

SRP £299
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